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ANALYSIS OF PRODUCTION CONSTRAINTS AT NADEP ALAMEDA; A TQL APPROACH

by

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June, 1993

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W. Edwards Deming introduced the idea of a systems approach to management as a means of looking at a network of processes as a whole. This thesis follows such an approach in looking at management systems, human factors, policies, causes of observed problems and production constraints, at the Naval Aviation Depot (NADEP) powerplants division at Alameda, California. This thesis uses the Theory of Constraints as espoused by Eliyahu M. Goldratt, as the guiding theory for analyzing barriers to throughput. The analytical models were developed using linear programming and a queuing network. Throughout the thesis an approach of looking at the whole system first before focusing in on problem areas is used. Ideas for preparing depot level maintenance databases for further evaluation by computer analysis are given, as well as potential areas for improving the system under which the NADEP operates.

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ANALYSIS OF PRODUCTION CONSTRAINTS AT NADEP ALAMEDA; A TQL APPROACH

by

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of the requirements for the degree of

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ABSTRACT

W. Edwards Deming introduced the idea of a systems approach to management as a means of looking at a network of processes as a whole. This thesis follows such an approach in looking at management systems, human factors, policies, causes of observed problems and production constraints, at the Naval Aviation Depot (NADEP) powerplants division at Alameda, California. This thesis uses the Theory of Constraints as espoused by Eliyahu M. Goldratt, as the guiding theory for analyzing barriers to throughput. The analytical models were developed using linear programming and a queuing network. Throughout the thesis an approach of looking at the whole system first before focusing in on problem areas is used. Ideas for preparing depot level maintenance databases for further evaluation by computer analysis are given, as well as potential areas for improving the system under which the NADEP operates.

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A special thanks to Professor Linda Wargo who reviewed and edited the Seven-M tools and Mike Tomsicek of Network Dynamics who loaned me a commercial copy of MPX.

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I. INTRODUCTION

A. OBJECTIVE

This thesis will follow a Total Quality Leadership (TQL) framework to look at productivity issues at the Alameda Naval Aviation Depot (NADEP) powerplants division.

> Total Quality is based upon managing organizations from a systems perspective, using employee knowledge, process measurement, and scientific methods to optimize the quality dimension of organizational performance. Quality in such an organization is defined by its customers. [Ref. 1]

Beyond the framework, the objective of this thesis is to combine both qualitative and quantitative tools to improve processes of a production system at NADEP Alameda. The tools will be applied in such a way as to first view problems in the context of the overall system and then focus on specific areas, with the goal of evaluating where improvements should be made and how much they will be worth.

B. RESEARCH QUESTIONS

Can production systems currently using TQL theory and Theory of Constraints (TOC) be improved strategically through combining group consensus tools and computer-aided analytical tools? A secondary question is: Can the benefits of various analytical tools be combined to greatly improve the analysis of a production system while minimizing the cost of evaluation?

C. SCOPE, LIMITATIONS AND ASSUMPTIONS

This thesis will have a broad scope in following a systems approach to TQL. Any element of the system that is strategically important to improve productivity is a part of the problem being considered. To maintain an emphasis on the whole process much of the detailed analytical work is placed in the appendices. A systems approach to TQL, drawing on various management theories as appropriate, remains the central theme throughout this thesis.

D. METHODOLOGY

Nine on-site trips were made to NADEP Alameda for data collection and discussion with key personnel. Input for the Seven-M tools were obtained from eight individuals as well as from discussions with more than a dozen workers on the shop floor. The depot's Master Data Record (MDR) database was the key source of labor time information used in the linear programming (LP) model and the queuing network program. Results were checked against the experience of key individuals.

E. STRUCTURE OF THE THESIS

Chapter II gives the background and a short case history of the powerplants division at NADEP Alameda. Chapter III uses a set of group consensus tools to divide problem areas into causes and effects, and to break the major causes into component parts. Chapter IV describes the key concepts of the Theory of Constraints (TOC). It looks at the key issue of system throughput in light of human factors that affect batch size. Chapter V presents the analysis of throughput, aided by linear programming and a queuing network program. Chapter VI looks beyond the production constraints to issues that would improve the system behind the powerplants division. Chapter VII contains a summary of the thesis and recommendations.

II. CASE HISTORY, NADEP ALAMEDA POWERPLANTS DIVISION

This chapter will set the real-life context for the research conducted. The purpose is to provide the reader with a feel for the barriers, frustrations and communication difficulties that are common to the Naval Aviation Depots. Despite these elements, success is possible, and has been well documented in the case of the powerplants division. As shown in Appendix A, the powerplants division has improved key TOC indicators of success over the past several quarters.

Their success has been coming from dealing with the productivity issues within their sphere of control and those that seem to affect productivity of their major products the most. As has been pointed out to the author by the Division Head, Jerry Ghiselli, there are hundreds of quality and productivity problems in any organization at any given point in time. Since time and money are finite, focusing on those issues that are strategically important, first, is the most successful way of employing TQL. As the system is improved however, strategically important areas for improvement may become harder and harder to find by simple observation. Anticipating where strategic improvements can be made, in advance of the effects of schedule changes is also extremely difficult to do.

A. BACKGROUND

The Navy uses three levels of maintenance: Depot (comparable skill and facilities to the original manufacturer), Intermediate (high volume, less in-depth repairs) and Organizational (trouble-shooting and replacement of parts). Depot Level Maintenance is the most in-depth level of maintenance performed by the Navy.

There are six Naval Aviation Depots (NADEP's) in the U.S. Navy. They are located at Naval and Marine Corps air stations at Alameda, CA; San Diego, CA; Pensacola, FL; Jacksonville, FL; Cherry Point, NC; and Norfolk, VA[1]. The NADEP's provide maintenance, engineering, and logistics support to the Fleet. They repair aircraft, engines and components for the Navy, other Department of Defense activities, and certain allied nations.

According to one of their public relations brochures NADEP Alameda is capable of repairing more than 12,000 individual components. To do this job NADEP Alameda employs over 3,000 employees. From a financial perspective it expends and receives $400 million annually from a revolving

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[1] As of March 1993 the NADEP's at Alameda, Pensacola, and Norfolk were on the DOD base closure list. By May 1993 all six NADEP's were candidates for closure, from which three would be chosen.

fund (the Navy Industrial Fund). In light of a perceived reduced threat of war, NADEP Alameda is facing possible shut down in the near future. Even if somehow spared from closure, it will face significant reduction of personnel.

Like private sector counterparts all NADEP's are currently facing forces of change and competition. Cutbacks in personnel and funding, and an aging pool of experienced workers put constraints on production. New technology, information systems and computer-driven analytical tools, require continuing education of the work force and divide the organization into increasingly detailed levels of specialization. Special terms, acronyms and lingo become the norm of conversation within specialty areas, which outsiders would find as formidable as learning a foreign language. This makes communication across departmental lines especially difficult. The following case should help the reader gain a closer understanding of the many challenges facing NADEP Alameda managers.

B. CASE HISTORY (NOVEMBER 1992)

The Powerplants division employs roughly 340 personnel working on day-shift (0615-1445) and 50 on swing shift (1445-2315). These workers support TF-34 and T-56 engine overhaul programs and a components program. The TF-34 is used on the S-3 and A-10 aircraft, while the T-56 is used on

E-2, P-3 and C-130 aircraft. The divisions' chain of command is shown in Figure 2-1.

Before Ghiselli became the head of 961 Division (T-56 Engine Division) in September 1992, he had worked in the Total Quality Leadership (TQL) office at the Depot for two years. Ghiselli was a part of the new leadership movement in the production management field. This movement sought to integrate the ideas of the best thinkers and authors

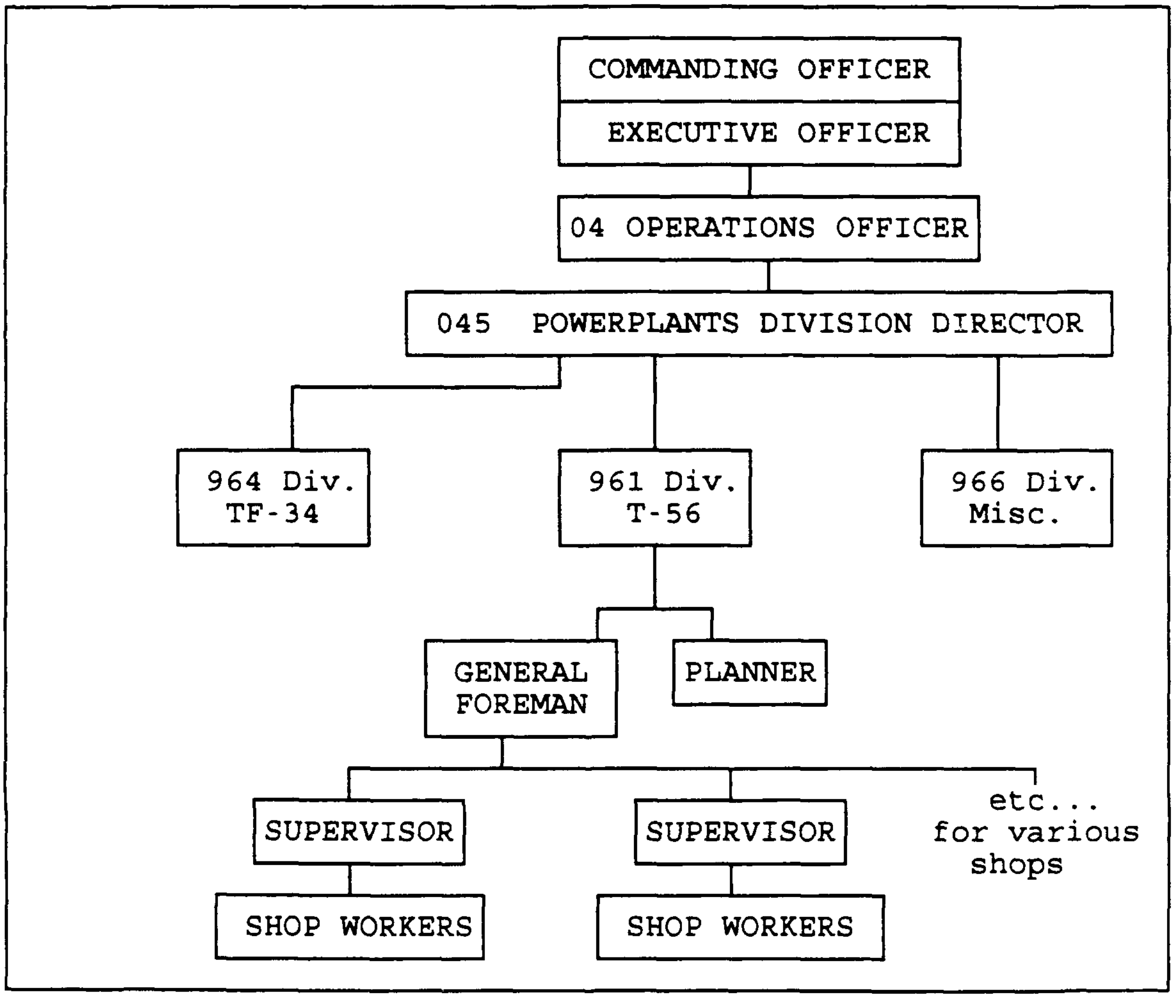

Figure 2-1. NADEP Alameda Powerplants Organization

concerning TQL and ongoing improvement. He was well versed in principles of statistical process control, Deming's teachings on management and Goldratt's theory of constraints. What made him effective was that he applied these principles in the operational planning and improvement of the T-56 engine/component overhaul program.

Results of decreasing work-in-process (WIP) and controlling inductions were not yet showing by November 1993. It would take another quarter before increases in sales[2] and decreases in turnaround time for the component program would be seen, as shown in Appendix A. There are several reasons for a full quarter lag before improvements manifest. In switching to a TOC environment, where the goal is to sell approximately what you bring in, you must lower the overall inventory. You end up selling old WIP which has been in the plant for a long time already, during the transition period. You must have patience to wait for the indicators to improve as you drain the system of old units. [Ref. 2]

1. Real Life Problems

Disturbing stories about the division prior to Ghiselli's arrival existed. For example, a worker who had a grudge against "the system" or their supervisor, might throw

[2] Sales is the term used by the NADEP to refer to "completing a component or engine and transferring it to the supply system."

away tracking documents, called "OP-DOC's" or "MDR's." These documents contained critical information on the status of the part it was assigned to and is needed to enter labor time expended into the Master Data Record database. Some linked these reprisals to anger over a reprimand or a counseling write-up. While events like this were rare, such stories seemed to be used by people to explain the way they felt and served to explain why certain inefficiencies existed in the organization.

Ghiselli's approach to solve these problems would seem too indirect to some; very simply, he would reduce work-in-process and thus congestion, and improve processes to reduce frustration levels. Shops with the most flow going through them such as clean, blast and nondestructive inspection (NDI) would be primary candidates for improvement. Frustration with working conditions and overloading would also be more likely in these shops.

Communication barriers to process improvements were evident. Again, a rationalized story seemed to give meaning to the frustration a blast operator experienced. He explained how his request to correct a simple routing problem was ignored by Examination and Evaluation (E&E) personnel (those who he thought approved the change). Based on the fact nothing was done about his verbal request, he thought that E&E did not want the problem corrected, because the problem gave them work each time it occurred and thus provided job security. It turned out, after looking into the matter, that he needed to submit his idea in writing via E&E to Production Engineering. Otherwise, they would not be considered.

In fact, most workers seemed knowledgeable and eager to suggest process improvements. It appeared that an easy avenue of communication via their foreman did not exist in some shops such as clean/blast, and NDI. In shops where the foreman was knowledgeable and involved in TQL there was a good communication channel between workers and other areas of responsibility for the system.

2. TQL at NADEP Alameda

Most workers had high expectations of TQL and believed that leaders and managers should listen more to the ideas of employees. Some had current articles on the subject of TQL posted in their work spaces. One such article posted on a locker, had a note boldly scribbled over it stating how this organization did not live up. The article was on the subject of leadership serving the needs of the workers.

Most employees had a good understanding of what TQL was supposed to do for improving the system, because the NADEP had provided special training to "all-hands" in TQL four years ago. Unfortunately, it was easier to get the hourly workers excited about the goals of TQL, than it was to change the system and get everyone involved on board.

This became evident during a discussion with three key employees at the head Examination and Evaluation (E&E) office. An E&E official, an engineer and a documentation specialist (all roughly the same pay-grade) were in disagreement with each other over whether time standards for labor time should be listed on the Master Data Records (MDR's). The documentation specialist, was adamant that time standards were absolutely necessary. He lectured the rest of us on how efficiencies would be thrown off, and how workers needed to have these numerical guides to know how long the job should take. The other two agreed that time standards did not help workers and could distort the time they documented.

Deming is very clear on the subject of time standards:

> Rates for production are often set to accommodate the average worker. Naturally, half of them are above average, and half below. What happens is that peer pressure holds the upper half to the rate, no more. The people below the average can not make the rate. The result is loss, chaos, dissatisfaction, and turnover. Some rates are set for the achiever, which is even worse [Ref. 3].

A further problem with time standards is that they give workers a false signal of how long it should take to do the job when the standards are incorrect.

3. Measurements and Documentation

Several years ago the NADEP installed data input terminals, to document time spent on parts. Recently, those terminals were upgraded to work with a bar code reader. New MDR forms were printed with bar codes at steps where measurement of labor time was desired. The purpose of the system was to collect accurate data on labor time for individual components.

However, the computer network and individual bar code readers were so prone to fail, many people refused to use this system as it was designed. Logging into work sometimes took workers several tries just to get the system to accept the code on back of their ID badge. Terminals were not always close to the work areas, thus, workers would have to walk several dozen yards with the MDR in hand.

Many people spoke of how workers were currently misusing the bar code system. They explained how people wasted time at the computer terminals finding out what the standard times were and ensuring they documented at least that much time.

Many workers had a callused perception of change and were skeptical of the new procedures. Being innovative, they found ways to work around the system and document their work by reporting labor time all at once or reporting multiple jobs under one code.

4. Policies

As the following anecdote illustrates, policies can become a major constraint. A furnace operator, whose equipment failed frequently would not be allowed to repair the furnace even though most of the times he told the repair person how to fix it. That required someone whose job description was furnace repair technician. The furnace operator (who had the appropriate electrical skills background) was skeptical of submitting the idea that he be allowed to repair the oven when able to, because he assumed it would not even be considered. He believed that management did not have the power to make such changes to the system and policies under which they operated. He also suspected conflicts with the union that governs federal employees, over taking away another persons job.

Solving problems such as this are considered to be beyond the limits the NADEP managers are capable of changing. Managers and supervisors are trained not to waste their time on policy constraints outside their control (i.e. public sector rules and regulations). In many if not most cases, however, these problems can be solved within the system by applying TQL effectively.

In analyzing public sector organizations, Osborne and Gaebler in their national best seller *Reinventing Government* [Ref. 4], continually show that centralized command and control under the Federal Government limits the ability of an organization to respond to changes. Financial incentives via competition, for producing a quality product, combined with individual incentives for innovation are much more effective. One problem organizations under heavy bureaucratic rules face, is constraining innovation. At the very least, this makes implementing change more difficult. Recommendations on reinventing the underlying system, that the NADEP's operate under will be expanded on in Chapter VI.

III. THE SEVEN MANAGEMENT AND PLANNING TOOLS

In any organization the people who own the process and are closest to the work have the best understanding of how to improve the system. Deming says:

> The greatest waste in America is failure to use the abilities of people. One need only listen to a tape of a meeting with production workers to learn about their frustrations and about the contribution that they are eager to make.... Anyone would be impressed to observe how articulate most production workers are, in spite of the criticism of our schools. [Ref. 5]

This chapter will use a group consensus process improvement approach developed by Bassard [Ref. 6], to identify productivity problems. The Seven MP tools aid in assimilating a large and diverse amount of information and help solve problems uncovered. Three of the Seven MP tools will be used to help define the most important problem areas affecting the Powerplants division.

In comparison to this approach, a survey is one way of identifying important issues. However, unlike a survey, where the way the question is worded has a large sway over the response, the Seven MP tools help define the questions themselves. As a result the information obtained is more comprehensive. Appendix B shows responses to a small survey given to the group involved prior to using the Seven MP tools. The Survey covered the same issues, as understood at that time, that were investigated through the Seven MP tools.

To start the search for a process improvement the author possessed a competitive advantage in solving, a group was gathered to explore issues affecting productivity. As an outsider to the organization the author did not know what questions to ask, outside the ones shown on the questionnaire (Appendix B).

A. AFFINITY DIAGRAM TO IDENTIFY PRODUCTIVITY ISSUES

The team assembled consisted of cross functional members: a planner, a shop supervisor, a worker from the turbine shop, a material procurement person, and the Division Head. An Affinity Diagram, Figure 3-1 and 3-2, was constructed to aid the team in extracting the main issues and problem areas of the division.

The power of the Affinity Diagram is its promotion of creative breakthrough thinking. It helps avoid the problem of looking for only familiar solutions and patterns of thinking. The issue considered in the Affinity Diagram was how to double the production of a typical major product, the T-56 turbine rotor.

Figure 3-1 and 3-2 was constructed by a cross functional team from the powerplants division. These issues are applicable to increasing throughput on other components as

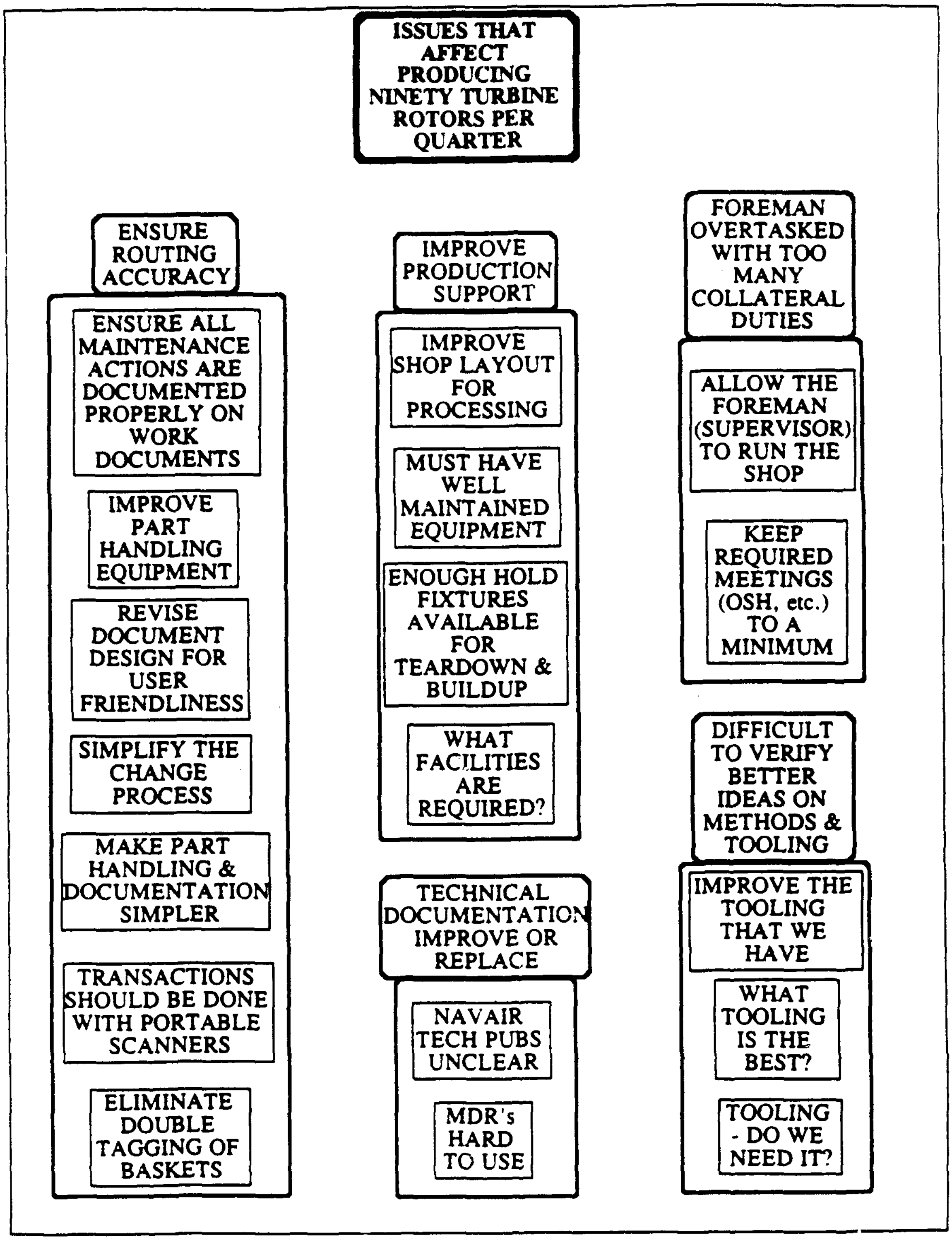

Figure 3-1. Affinity Diagram, Issues Affecting Productivity

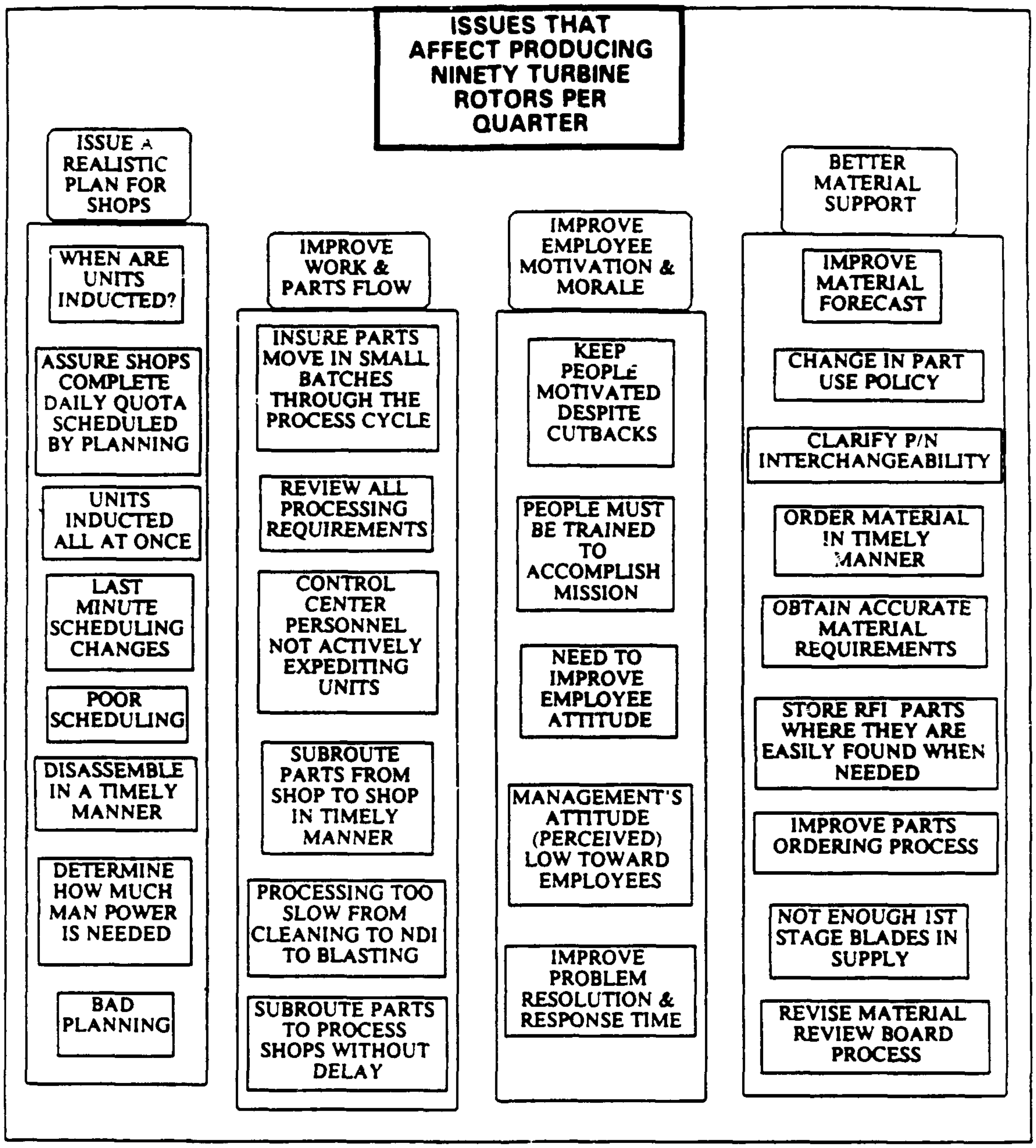

Figure 3-2. Affinity Diagram, Issues Affecting Productivity

well. The idea cards generated during the brain storming session, were grouped into categories by the team and given a summary heading, called a header card. The effect of pooling the team's knowledge together was to surprise some team members in the diagram that followed shown in Figure 3-3.

The issues that resulted from the diagram were a result of expanding our thinking to any possible issue that could affect productivity and then narrowing those 46 issues to nine categories. However, nine problem areas is still to diverse a group to select a process improvement effort from. There was a need to narrow our focus to the vital few that were responsible for causing the most problems to the system.

B. INTERRELATIONSHIP DIGRAPH TO PRIORITIZE ISSUES

The Interrelationship Digraph (ID) allows logical cause and effect relationships to become evident. The diagram is constructed by asking the group if a given issue causes or influences another issue. The greater direction of cause is shown with an arrow. A large number of outgoing arrows, suggest a major cause, while a large number of incoming arrows, suggest an effect or key issue. Using the header cards from the affinity diagram, interrelationships were checked for cause and effect in Figure 3-3.

After analyzing Figure 3-3 you will notice that "technical documentation" not only has the most outgoing arrows, but its outgoing arrows affect other major causes as well. Technical documentation affects the next major cause

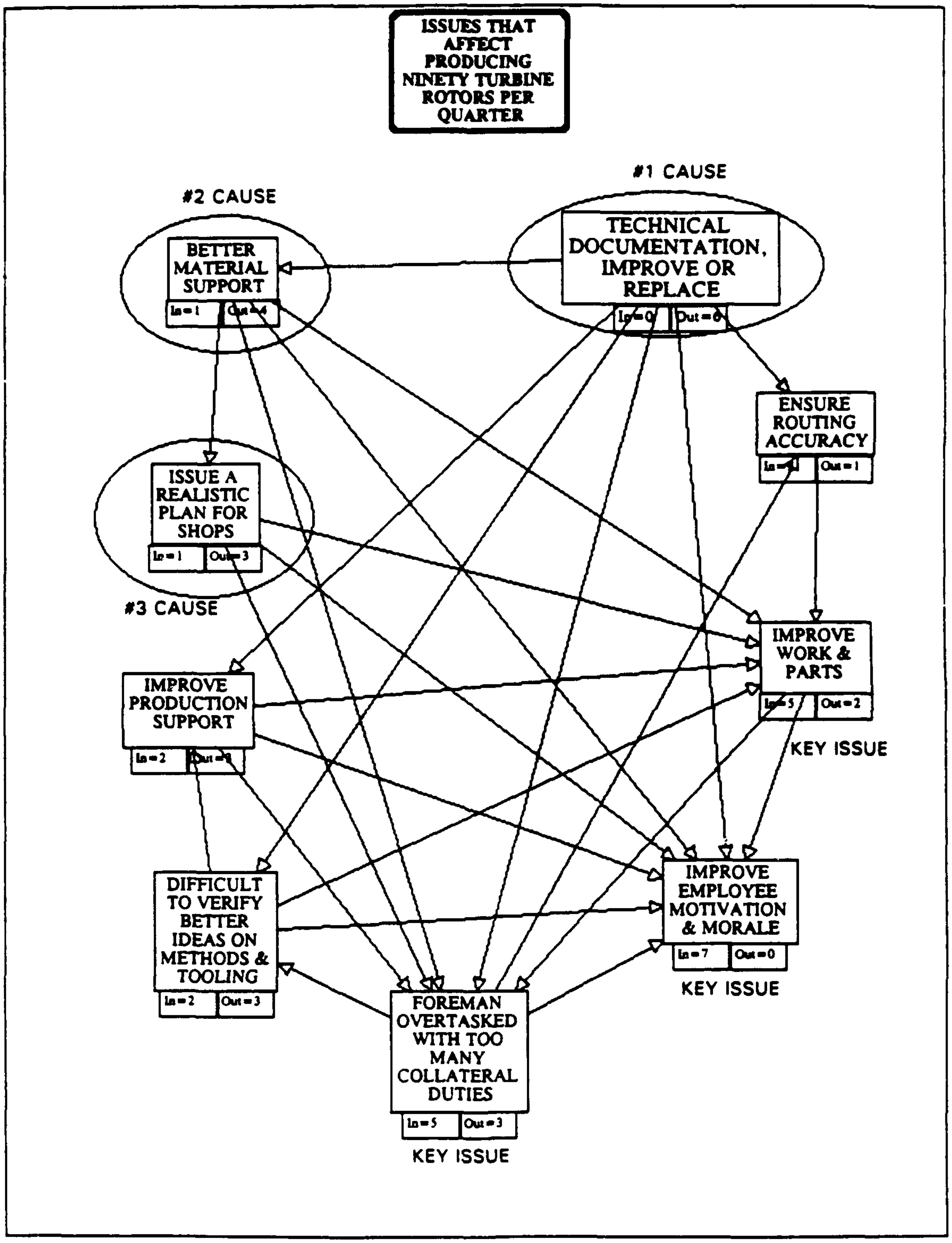

Figure 3-3. Interrelationship Digraph of Major Issues

"material support," and the top key issues of "improve work flow," "improve employee morale," and "foreman overtasked." The interrelationship digraph or ID, clearly shows that if you improve technical documentation, you will receive a spill-over benefit to each key issue and significantly improve the overall issue of doubling productivity.

The result of the two diagrams was to create a hierarchy of impediments to productivity:

#1- technical documentation;

#2- material support;

#3- issuing a realistic plan for shops.

To improve the key issues and the overall objective of improving productivity, the underlying causes of problems in the system must be dealt with. The need was now to break these major causes into component parts to the point where solutions could be implemented. To do this the tree diagram was selected as the appropriate tool to re-expand our thinking on the issues we had narrowed down to. In order not to waste the time of the entire group the remaining ideas and solutions were generated with only those persons related to the above three issues. Their ideas were then checked by others outside the group.

C. IMPROVING TECHNICAL DOCUMENTATION

Under a TQL framework it would be a mistake to use only an incremental approach at the expense of ignoring causes that can be improved on by fundamental changes to the system. Chapter VI will provide specific recommendations on changes to the entire system. However, at this point the tree diagrams are being used to work within the current system. Changes proposed are only changes allowed by current system mandates.

Figures 3-4, 3-5, and 3-6 show a Tree Diagram of the problems with technical documentation. Assignable tasks to fix these problems are listed at the extreme right-hand side of the tree diagram where appropriate. The breakdown of the problem of technical documentation was done with the

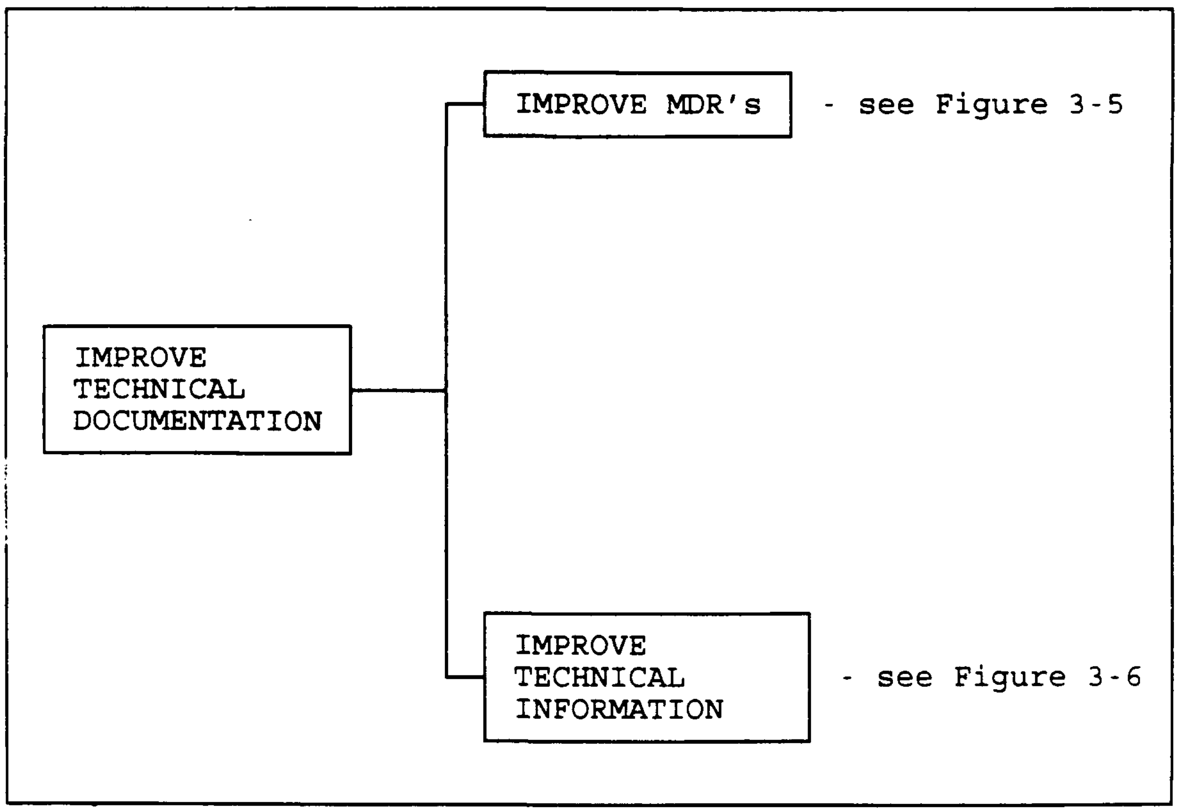

Figure 3-4. Problem Areas With Technical Documentation

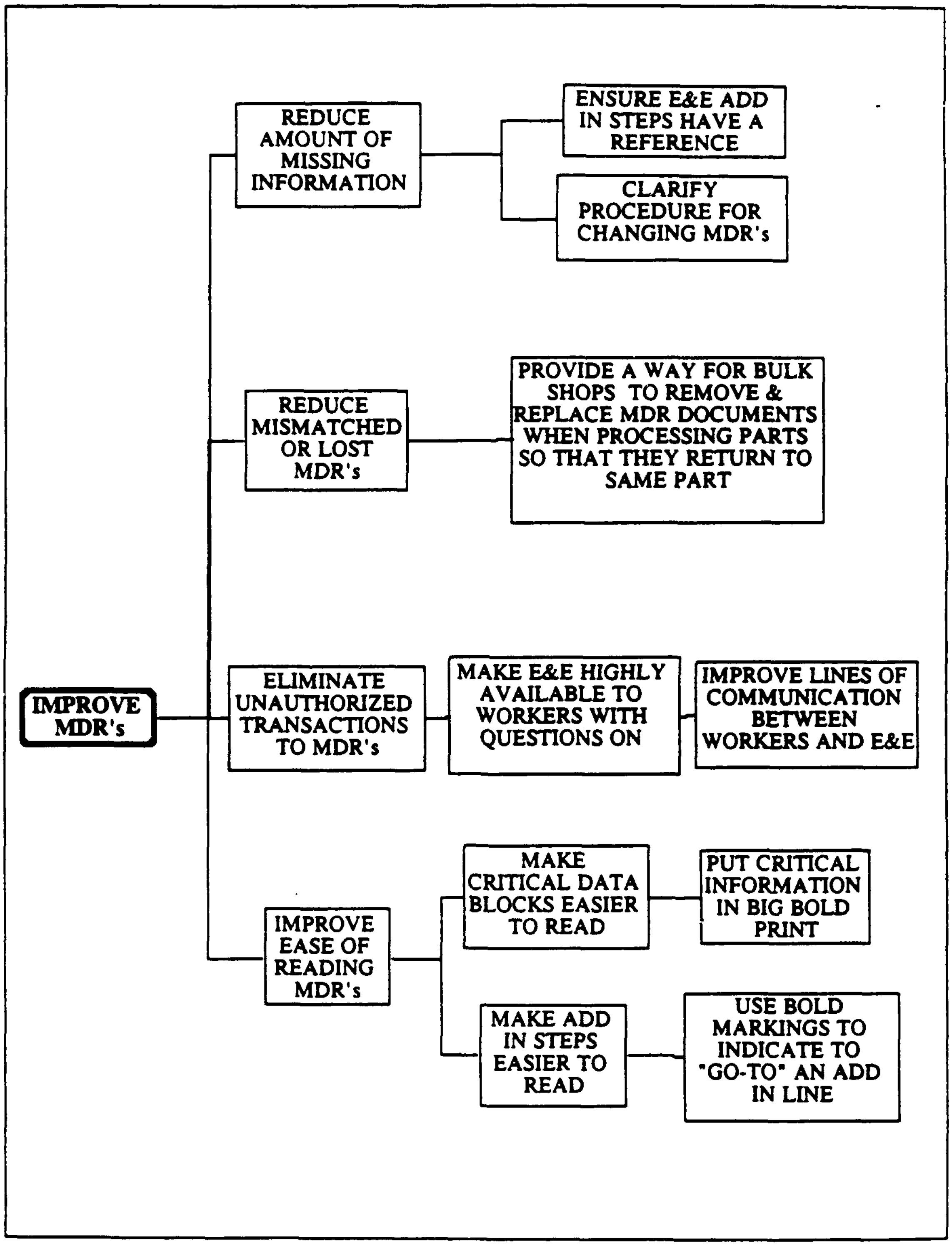

Figure 3-5. Tree Diagram on Improve Routing Document - MDR's

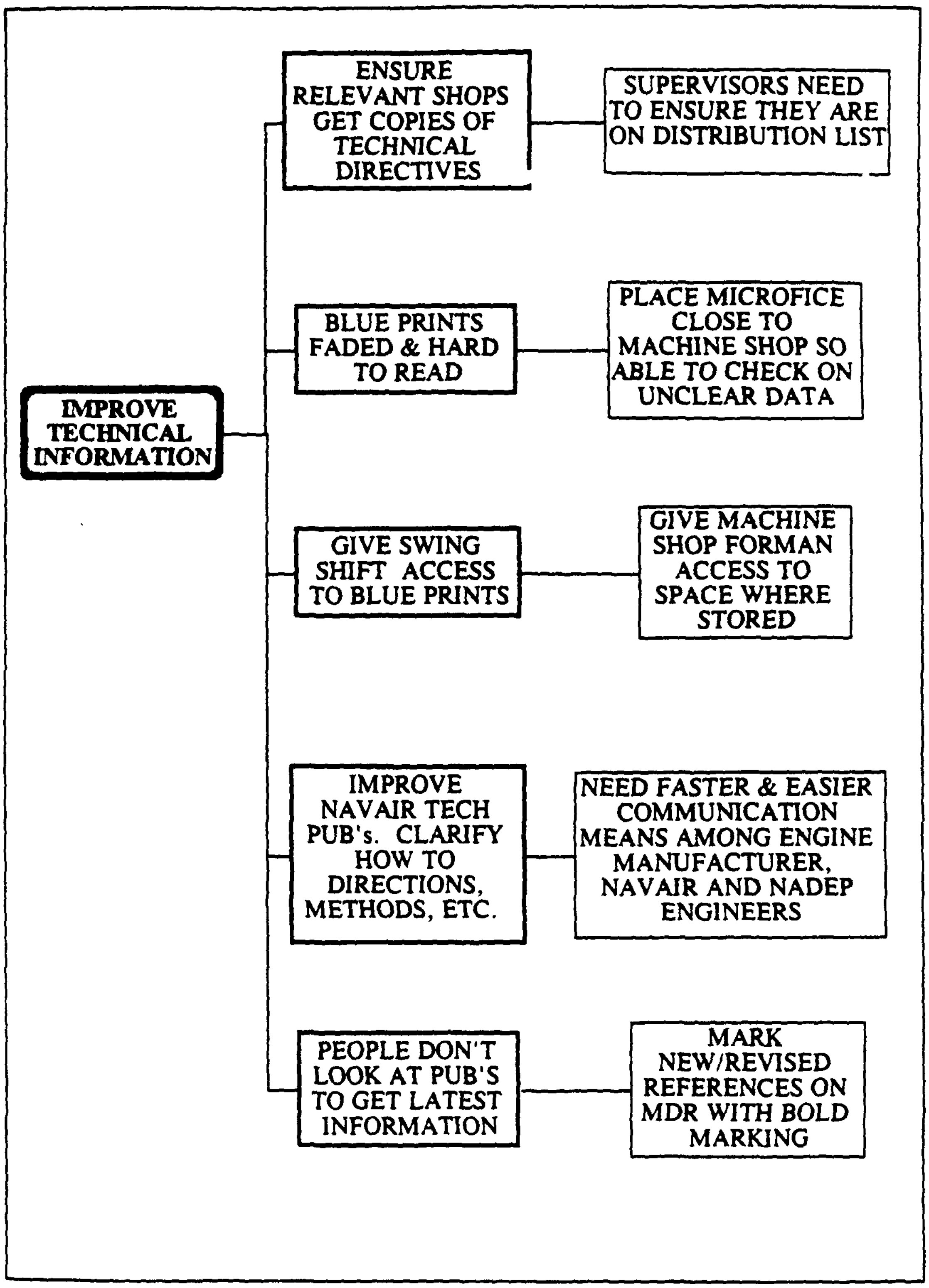

Figure 3-6. Tree Diagram on Improving Technical Information

expertise of a T-56 turbine shop supervisor, an expediter, a machinist, and an examination/evaluator (E&E).

The most important problem area under technical documentation was felt to be reducing mismatched or lost MDR's. Correction of this may require affixing a permanent, swivel type, metal tag to baskets for ease of reading. It also may require redesigning the MDR form for ease of reading (tag number, information, etc.). It was felt that this one correction alone would save many parts from being lost or delayed. Appendix C is a sample MDR tracking document. If the form can be made easier to read, parts won't be as likely to be misrouted. (Some parts get routed back to the same work center repeatedly or separated from the tracking document, causing delays.)

An equally important issue is being able to easily communicate process improvement changes to tracking documents through the complex NADEP system. The following actual situation further clarifies this need as applied to tracking documents.

1. Communication Barriers to Process Improvements

A T-56 compressor shop worker observed that he scrapped 70% of 14th stage vane assemblies due to corrosion and erosion. Observing that the Clean, Blast, and NDI shops were bottleneck's to workflow he realized it did not make sense to send these parts through those shops before his inspection. NDI can illuminate cracks, but it cannot evaluate corrosion or erosion. He told his foreman that routing the vanes directly to his shop from disassembly first, would eliminate 70% of Clean, Blast, and NDI's work on this type part. He heard nothing, so he mentioned it again in a couple of weeks.

As nothing became of his suggestion he submitted a beneficial suggestion, "Beni-Sug." He received word back months later that his suggestion was turned down because it was a normal part of his job. Later, still determined to help the system, he stopped in on a process improvement team reviewing MDR's. They loved his idea and got it approved.

The bottom line, is that there are other ideas out on the shop floor awaiting a responsive channel to be communicated through. If managers, foremen and supervisors are continually fighting immediate fires, there is little time left for them to focus on process improvements. There needs to be a willingness to forgo short term fire fighting, collateral duty program meetings, evaluation writing, and other administrative functions to have the time to listen and work on process improvements which hourly workers are ready and able to communicate. Having an active, easy way, to propose changes to part routings is probably the best place to start.

It happens that there are other parts (blades and vanes), that NDI rarely ever turns up a crack on. The vane/blade workers know where to look and how to spot these types of cracks. These workers say they cannot rely on NDI to catch even 50% of cracks existing in their blades. The NDI workers talked to, agreed that many parts are needlessly sent to NDI for various reasons: obviously bad parts, parts that can be inspected better by a specialized shop, or even just rarely defective parts.

Ideas are often proposed by workers that never get communicated to where change could be effected because of a known policy to those in the chain of communication. As an example, consider proposing to put functions such as cleaning or NDI into individual shops. Such a move could help alleviate the cleaning and NDI shops as bottlenecks - they are also observable as such. Appropriate shops might include the various compressor and turbine blade repair shops and machine shops. An immediate barrier that could stop the communication process would be difficulties in meeting hazardous vapor regulations. There is again for this reason a need to be able to clearly and easily communicate ideas to those who have the knowledge and power to evaluate and implement them.

D. IMPROVING MATERIAL SUPPORT

Material support at NADEP Alameda is continually under review for process improvements and has undergone several improvements in recent months. Many of the issues raised by production workers focused on improving throughput and reducing lead time, however, there are trade-off considerations such as material costs, and safety as well. A thorough analysis of material support functions is beyond the scope of this thesis, however, a tree diagram of current problem areas and possible resolutions is shown in Figure 3-7.

The most important issue in this area, could very well be expanding E&E's role in inspecting parts as they are disassembled. There is more of a benefit to the system than just getting obviously damaged parts on order sooner. In an overhaul operation removing an unrepairable part from the overhaul process early saves the processing time of each work center along its route. Thus, one part an E&E inspector removes from the system at an early stage saves numerous other work centers needless processing time.

E. IMPROVING PLANNING

Several problem areas listed in Figure 3-2, under issuing a realistic plan for shops can only be eliminated by working closely with customers (ASO, NAVAIR, etc.). These would include reducing last minute scheduling changes and improving demand forecasts of aging equipment in the Fleet. Other areas have been greatly streamlined in the Powerplants

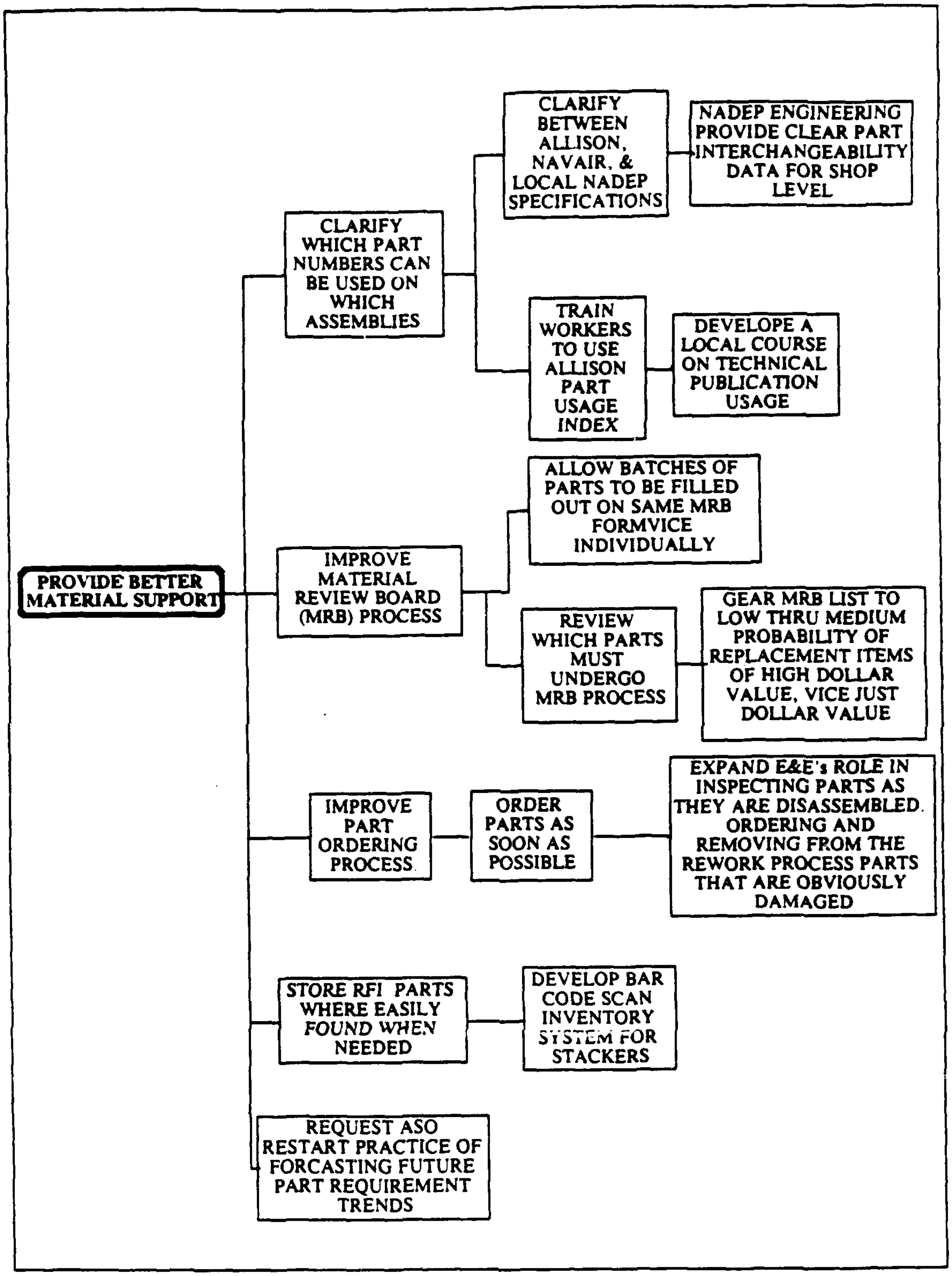

Figure 3-7. Tree Diagram: Provide Better Material Support

division, such as deciding when and how many retrograde[3] engines or components are inducted at a time.

Most scheduling and planning issues are not easily resolved. How much manpower, overtime and the number of machine processing hours required is affected by many factors. The product mix for the quarter and the demand each product places on resources (machines) has a chain reaction effect on the system and results in work-in-process in waiting lines (queues).

Thus, the problem of planning and the problem of improving work flow are interconnected. One cannot be improved without improving the other. Linear programming, a rough cut approach, compared to MRPII scheduling systems, will be pursued in Chapter V, to help resolve this planning/throughput dilemma. However, before that, the managerial framework under which these process improvements are currently being made at NADEP Alameda will be considered.

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[3] The term retrograde is used in naval aviation to refer to a component that needs repair.

IV. THE KEY ISSUE: IMPROVING THROUGHPUT OF THE SYSTEM

The Powerplants Division is composed of thousands of tasks performed by about 300 workers. These thousands of tasks, however, are grouped into only several dozen processes. Processes are directed at accomplishing a particular outcome, such as cleaning or non-destructive inspection of a part. A group of processes are connected in such a way as to form a system, such as the overhaul of a component or an entire engine. The effort or performance of each individual thus must be managed such that the overall system is optimized.

To manage this production system, the Theory of Constraints, as espoused by Goldratt [Ref. 7] provides a management methodology and new measuring units. To provide the background and show how NADEP Alameda Powerplants Division is pursuing throughput and lead time reduction the following is quoted from NADEP Alameda's own training handbook [Ref. 8]. This theory will guide the choice of computer aided tools and analysis performed in Chapter V.

A. THEORY OF CONSTRAINTS

In most companies the methods of measuring "success" are Net Profit and Return on Investment -

standard accounting tools. In using the Theory of Constraints, measurements are based on **Throughput**, **Inventory**, and **Operating Expenses**. These are defined as follows:

Throughput - The rate at which the system generates money through sales. Note that the key is "sales". Items that are produced/reworked that are not for a specific customer (and become simply warehoused) are not considered as throughput.

Inventory - All the money the system invests in purchasing things the system intends to sell.

Operating Expense - All money the system spends in turning inventory into throughput. This is all costs, including labor, of producing/reworking the product.

There are five logical steps which will allow you to focus in on the specific physical constraints in your area:

1. <u>Identify the constraints</u>. This also involves placing a priority on the constraints according to their impact on the overall goal of the company business plan.

2. <u>Decide how to utilize the system's constraints</u>. Determine how to manage the constraints. Remember that these constraints are "things" that limit the rest of the operation but are of vital necessity and as such must not be wasted.

3. <u>Subordinate everything else to the utilization of the constraint</u>. This involves managing the constraints so that everything that the constraint requires is provided by a non-constraint. (i.e. if you determine a constraint to be the processing of material requests, then the area generating the material requests must do so in a complete and timely manner.)

4. <u>Elevate the system's constraints</u>. The limiting impact of the constraint must be reduced. Make the constraint visible and continue to highlight it, making it the "spotlight" of attention. With enough visibility and attention, eventually you will succeed in breaking the constraint.

5. <u>If you succeeded in removing a constraint, go back to step one and begin again</u>. Let each success be the beginning of another. Remember - the key is on-going improvement. When one constraint is removed, another will become evident.

One of the key tenets of Theory of Constraints is the reduction of batch sizes. The purpose of this is as follows: First, reducing batch sizes decreases lead time. Secondly, it increases throughput if setup time is not significant or can be reduced also. Throughput is the most important measurement of "success" under this theory. Thirdly, decreasing batch sizes reduces inventory, the second most important measurement of success.

To optimize the system as a whole, subcomponents of components must be ready for assembly at the right time. When parts are collected by a particular work center and processed all at the same time, further assembly points may be delayed because of lack of one part, while having an abundance of another. Small batches thus result in the shortest lead time in getting products out the door. Additional benefits include detection of defects by the next processor or assembly point, before a larger number of units have been defectively processed.

Before going on to an analytical analysis of constraints and lead time there may be forces being exerted, inherent in the underlying system, which will work against the effort to process items in smaller batch sizes. Thus, before focusing in on specific constraints, with computer aided analysis, an attempt will be made to look at the overall picture from a human behavior standpoint.

B. PUSHING FOR SMALLER BATCH SIZES

A description of the current batching tendency is found in the following example. Currently approximately one T-56 engine is disassembled per day. The controller for the disassembly shop delivers the components to cleaning in lots of one set of engine components per day. Inlet guide vanes that had been disassembled on 4, 5, 6, and 7 February were found together at the induction area of the NDI[4] shop on 12 February. The vanes are processed from disassembly through cleaning, blasting and NDI. Since these shops are bulk shops[5] the steps are not documented with a date stamp. Thus it is impossible to know where they collected into a batch of four. Whether they were batched up at cleaning or blasting is not the point however. The question is: What is causing parts to batch up throughout the division?

1. Force Field Analysis of Batch Sizes

There are many reasons, or forces, that push workers to batch parts into groups. Since the management at the Powerplants Division has been trying to get workers to move

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[4] Nondestructive inspection (NDI) or nondestructive testing (NDT) are synonymous. They are performed in the powerplants division using eddy current, florescent penetrant and magnetic particles as a means to detect cracks and sub-surface flaws.

[5] Bulk shops are the shops that process parts in larger quantities and are not required to document hours expended on the component. Examples are Clean, Blast, NDI, Plating and Heat Treat.

parts in small batches, it is worth looking at from a human perspective. Some forces, are obviously blocking the effort to promote this change.

Kurt Lewin developed a technique called "Force Field Analysis."[Ref. 9] In it he proposed that "driving forces" move a situation toward change, while "restraining forces" block that movement. His diagraming technique was employed here to depict what forces workers felt were driving them toward particular levels of batching. In doing the diagram the following steps were taken:

STEP ONE. Identify the change group. Through talking with various individuals, four shops were selected as the culprits for batching parts into groups (and thus most in need of change to reduce batch sizes). The shops were the machine shop, cleaning, blasting and plating shops.

STEP TWO. Clarify the goals of the change with the change group. A brief explanation was given to each member interviewed of the reason that lower batch sizes were desirable. Also, a desired target was set to a batch size equals one.

STEP THREE. Information on the driving forces and restraining forces and their effect on the behavior of batching, was gathered from the interviewees.

STEP FOUR. The forces are analyzed for factors (underlying reasons, policies, etc.) that may produce these forces.

STEP FIVE. A change strategy to reduce restraining forces is devised. According to Lewin's theory, if driving forces are increased to push batch sizes toward one, the system will be subject to more pressure. If these added forces are then released, the system may recoil to a worse level than it was before the additional driving forces were increased.

Figure 4-1 is a Force Field analysis on change to the current tendency to batch up parts at process stations. The diagrams were drawn from interviews with a machinist, a cleaning operator, a blaster, and a former plating technician.

A study of the figure shows the following observations: Workers are behaving in a rational and innovative manner to maximize the benefits as they are affected and as they perceive them. For instance, being able to process two parts at the same time in the same cleaning tank or taking advantage of a one hour setup time on a grinding machine is clearly more efficient to the worker when the parts are piled in the induction area.

There is a limit on how much incoming work can pile up in front of a shop area without impeding work flow to other shops. If batching is necessary to speed up clearing the induction area in front of a shop, the shop may be a bottleneck and legitimately need to group parts into batches just to keep up.

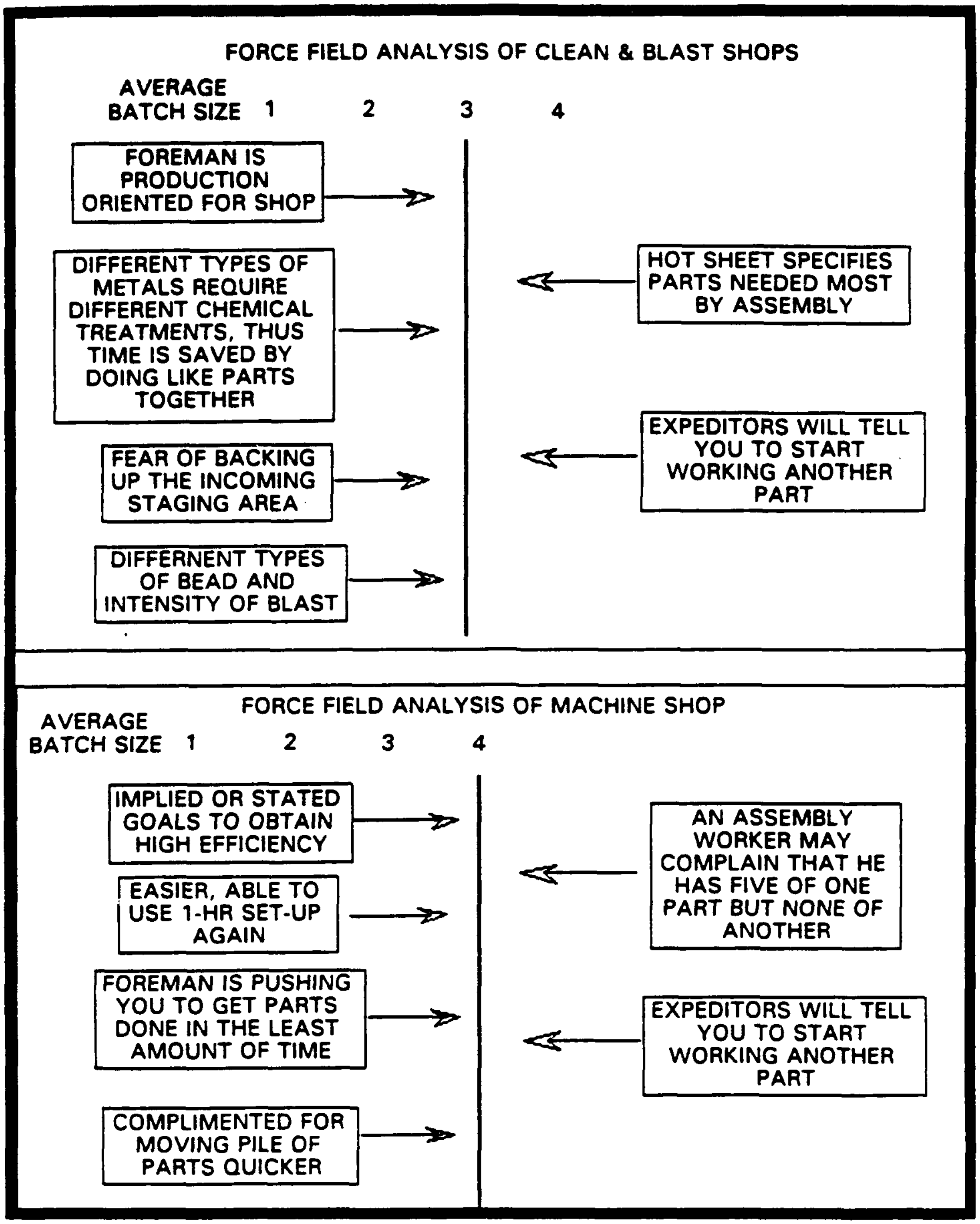

Figure 4-1. Force Field Diagram: Reducing Batch Sizes

Another human tendency to be considered is that if a batch of four parts are received, intuitive reason suggests that they should be processed and sent out in that same quantity. It is the responsibility of production control (called controllers at Alameda) to direct the batches be divided and transferred early. This is known as a transfer batch.

Chapter V will show how a queuing network program can help evaluate the effect of batch sizes on work-in-process and lead time. The queuing program can also provide a tool for evaluating factors such as set-up times and transfer batches. Providing key foremen the training to use such an analytical tool could increase their confidence to uphold policies on small batch sizes. A foreman needs to be confident that his work center has the capacity to process the quarterly demand, at specified batch sizes. He or she would then be more willing to sacrifice local efficiencies for improving the throughput of the overall production system.

2. Batching and Performance Evaluations

Finally, it is easier to change policies on efficiency goals which promote batching, than it is to change mind-sets. For years foremen have been evaluated on efficient machine utilization, as part of their annual performance write-up. Traces of this "efficient machine utilization" mind-set still remains. Changing this mind-set will take more than one time issuance of verbal or written policy. The Theory of Constraint training NADEP Alameda provides to workers as cited, has done much to correct this problem already and will continue to improve as more people are trained.

New incentives are needed to reduce leftover tendencies. An old incentive structure still in effect that may be hurting the effort to reduce batch sizes is the performance evaluation system. According to Deming [Ref. 10]: "One of the main effects of evaluation of performance is nourishment of short-term thinking and short-time performance." Goldratt [Ref. 11] says: "tell me how you measure me and I will tell you how I will behave." Goldratt shows how local performance measurements of productivity, profitability and unit cost accounting, distort the goal of the company as a whole.

One of the criteria currently used in performance evaluations of shop supervisors and workers as listed on the divisions customized evaluation form (NAVSO 12430/10) is:

- No more than one documented incident of unsatisfactory utilization of personnel or improper scheduling of work which adversely impacts the section scheduled performance or indirect performance below 90% at section level.

It is possible this criteria could contribute to pressure for larger batch sizes in a particular shop.

Additionally, trying to attain high utilization of personnel might prompt a foreman to keep his people busy processing parts not needed. If nothing else it is conflicting policy.

This chapter has addressed the importance of considering human factors when designing production control policies for two reasons. First, analyzing "where it hurts" from a human perspective will lead to better understanding of bottlenecks and policy constraints. Secondly, policies such as batch size goals and measurement of performance must fit together with consistency. It also seems to make sense to solve the human side of a problem before employing expensive analytical techniques, which may be thrown off by the human factors.

V. ANALYTICAL ANALYSIS OF THROUGHPUT AND PLANNING

This chapter discusses an analytical approach to improve planning and evaluate process improvements. Improving planning was identified in the Interrelationship Digraph, Figure 3-3, as the third most important detriment to productivity. Linear programming will be used to look at the overall picture and solve for both an optimal product mix and to identify constraint resources. A queuing network program will then be used to further focus on processing constraints. The products considered will be selected according to the Pareto principle. The *major products* (the vital few) the division produces will be segregated from the *trivial many*. In doing so, the fewest components that take up the majority of labor time will be selected. An *80/20 principle*[6] will be used to collect the minimum amount of information necessary for a large degree of accuracy.

A. LINEAR PROGRAMMING (LP)

An LP package called STORM [Ref. 12] was used to evaluate the optimal combination of components to produce, given the limited labor resources the NADEP possesses. The intent of the LP is to select a product mix,

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[6] This is a rule of thumb stating that 20% of the parts will provide 80% of the pertinent information.

which maximizes revenue. The revenue earned by the NADEP is based on the labor hours put into the component, thus the LP will physically maximize labor hours achievable. At the same time, the need the Fleet has for the part, which is reflected in the number scheduled by ASO, also needs to be considered by the LP.

1. Linear Programming Model

The LP objective function of the LP Model is shown in equation (1).

$$Max\ z = \sum_{i=1}^{n} C_i\ X_i \tag{1}$$

It will be subject to 28 constraint equations for labor time[7] shown in equation (2).

$$\sum_{i=1}^{n} t_{ij}\ X_i \leq R_j \tag{2}$$

for j = 1, 2... 28

$X_i > L_i > 0$ and $X_i < U_i$

The terms of the equations are defined as follows:

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[7] Processing times on specific equipment were not available on any of the NADEP databases. Management agreed that working with labor time was the most important constraint category between processing time and labor time - especially in the climate of personnel cuts.

X_i - The quantity of the **i-th** product to be repaired, for **i** = 1, 2... 20.

C_i - coefficient equal to the summation of average expended labor hours over the past two years to produce one unit of the **i-th** product;

R_j - the amount of **j-th** resource time available (right hand side value of constraint equation) adjusted as necessary to account for component program components not considered in the LP[8];

t_{ij} - total labor hours to repair the **i-th** product on the **j-th** resource;

L_i - lower bound for the **i-th** product;

U_i - upper bound for the **i-th** product (the number of retrograde parts scheduled for repair by ASO).

The LP, as run in the thesis, is composed of 18 major components plus the T-56 and TF-34 engines, for a total of 20 major products represented. However, the possible choices for the set of **i** components for future quarters is up to 97 different components.

Each quarter the planner would activate as many of the components of the 97 represented in the LP, as necessary

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[8] Decreasing the right hand side of constraint equations is a method of compensating for demands on those resources not considered. Due to not being able to match components from the engine program to the component program directly, the resulting hours represented by the components chosen were larger than they would be with component program data. As a result the right hand sides were not decreased by the 20% of product labor times not considered.

to obtain the greatest percentage of the total possible[9]. Any remaining time would be subtracted from the right-hand side of the appropriate constraint equations.

2. Identifying Major Products

To identify the *major products*, labor time and quarterly requirement data was gathered. The labor time was downloaded from the MDR database. The output included the workload standard hours (STDHR), actual expended hours, and the Induction Occurrence Factors (IOF) for each component and operation step conducted on the T-56 and TF-34 engines at the NADEP during the last two and one half years. Workload standard hours for one component that under goes overhaul operations **i** = 1 through **n**, are computed by a group of equations. They have been combined as shown in equation (1) as a single equation, where one particular component undergoes operations of **i** = 1 to **n**.

$$STDHR = \sum_{i=1}^{n} \frac{(OPNSTD_i) \times (IOF_i)}{(POF) \times (PPF)} \qquad \textbf{(3)}$$

Operation standard hours (OPNSTD) are set by Methods and Standards for each step in the overhaul process. The effect of the IOF (a decimal) is to decrease the OPNSTD for

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[9] A commercial LP package would easily handle all 600 components the division is capable of working for the component program.

the percentage of time the part does not actually go through the overhaul step. The OPNSTD is then increased by the percentage of time the component is not completed by dividing by the Production Occurrence Factor (POF). The POF is the proportion that accounts for the scrap rate of entire parts. The OPNSTD is then increased by dividing by a depot efficiency factor, a constant, known as the Planned Performance Factor (PPF). The PPF for NADEP Alameda is .91 which is a means for boosting revenue to the amount required to break even under the rules of the Defense Business Operations Fund (DBOF). The summation of the above results for each operation performed on a component is the workload standard hours (STDHR) that the Depot charges customers.

To identify the *major products*, the second quarter FY-93 production schedule requirements, obtained from division planners, were multiplied by the Workload Standard Hours for the components scheduled (see Appendix D). This resulted in a *total demand* of resource time column. The database was then sorted on the *total demand* column and the products that constituted the top 80% of overhaul time were selected as the *major products*. As a result 18 components were selected out of 86 representing 60,000 workload standard hours for the quarter's component program.[10]

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[10] The Powerplants division works parts under a "components program" (overhaul of individual parts for the supply system) and an "engine program" (complete overhaul of an entire engine). Repair time for the two engines (T-56

Appendix D shows the components program schedule for second quarter FY-93, and those that fell in the top 80% of labor demand.

3. Hypothetical Schedule

Two factors resulted in the use of a hypothetical schedule vice the actual second quarter schedule. First, the data for the component program was converted in a very rough manner from engine program data. This was necessitated because getting the data for all components was not feasible.[11]

The second reason was that the right hand side values of the labor constraint equations were not decreased as they should have been to account for the 68 components out of 86 that were being ignored. This approach was being taken because the Linear Programming package was limited to 100 variables and 50 constraints. Without the data for the 20 percent of the second quarter schedule that was ignored, the schedule was meaningless. As a result, a hypothetical schedule was chosen to illustrate planning methods in the remainder of the thesis.

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and TF-34) were calculated without deleting minor components, however overhaul time expended data rather than Standard Workload hours were used.

[11] Actually, only the labor time for the 86 components scheduled during the second quarter would have been required. However, this would not have served future quarter planning needs, since there are 600 some components the division is capable of working.

4. Information Collection

The time to complete individual process steps for each engine component is measured by reporting through a bar code system into the Master Data Record (MDR) database. As explained earlier there are currently some problems in the user-friendliness of this system to workers entering the data. However, the alternative of using workload standard hours, would be even more inaccurate. For this reason, despite some inaccuracies, two years of recent history records were downloaded and summed according to labor time expended at each major resource. A report called the MDR Match History Report, which matched two separate databases (MDR and history records), was generated to show labor times for a given component and its sub-routed assemblies.

This report was downloaded to ASCII and put on a micro computer database (Microsoft Access). The major shops were separated from those that provided a trivial amount of time (a sum total of less than three hours of labor time for both one complete T-56 and TF-34 engine). These trivial shops deleted from analysis, not considered in the LP, are shown in Appendix E. The average labor time values for each component over the last two years were then extracted from the database. The Induction Occurrence Factors (IOF) were multiplied by these times to yield the resulting time values t_{ij}. These values were then imported into the LP model after being put into a cross tabulated format by Microsoft Excel, as shown in Appendix F.

5. LP Model Output

The results of the LP model maximizing the objective function, given the hypothetical schedule, is shown in Appendix G. As stated in Chapter III, Section E, the problem of planning the quarter's manpower requirements and resource demands is their interconnection to the quarter's product mix and workflow. The LP provides a connection with the first of these two factors - product mix. In the current environment of competition between NADEP's and private contractors it is imperative that NADEP managers know what products to compete for more of, and which to suggest ASO to contract out. Referring to Appendix G, planners would negotiate to produce less of the products that had a large negative shadow price. For example, forcing another High Power Turbine Module (225212060) into production would cause a decrease in total division output of 17.06 hours per week.

6. Analysis of Constraint Resources

Appendix H shows the type of information necessary for a cost/benefit analysis of increasing shop labor time (the right-hand side values of the constraint equations). The benefits half of such an analysis is shown for the constraint resources with the highest shadow prices

(Milling, NDI and cleaning). The parametric analysis shows the connection between resource time added and product mix by showing which products enter and leave the solution as the resources are increased.

The revenue generated would need to be compared with all the costs incurred (overtime, utilities, and qualitative factors such as personnel burnout). In the case of the Milling shop the shortage of labor is arbitrarily fenced. In reality, processing capability from other machine shops and flexibility of labor usage eliminate this constraint. In short, parametric analysis shows how spending money on increasing constrained resource time allows otherwise unused resources to be activated, resulting in additional production.

Appendix I is an example analysis of making improvements to processes. The process evaluated is a general reduction of the initial NDI/clean operation performed on most parts. In this analysis, specific components have not been identified for reduction, but rather a percentage reduction of labor time from all components demanding these resources is evaluated. This quick analysis provides a rough estimate of the value of pursuing this analysis further in detail. To perform this analysis accurately, specific components that could skip the initial NDI/clean operation and go on to a slack resource would need to be identified. The appropriate NDI/clean time would need to be removed from the objective function and the constraint equations.

As stated by a T-56 compressor shop worker (See Chapter III, Section C.1) many parts can not be effectively inspected by NDI. In addition, parts that rarely have a defect detectable by NDI could bypass NDI when it is a bottleneck. Those parts could go to NDI after going to one or more non-bottleneck shops whose processing operations make post-cleaning necessary (machining, etc). In addition to this specific proposal, a general approach to alleviate constraints near the beginning of the overhaul process would be to expand the role of disassembly personnel in examining parts as they are disassembled, or inducted.

The LP provides an analytical tool for evaluating proposals made by process improvement teams or individuals. Through the Seven-M tools many focused ideas were generated. In many cases these ideas will need to be further analyzed to determine their worth. A means of evaluating the worth or benefit of ideas, is especially necessary in light of tight budgets.

7. Conclusions of Linear Programming

In conclusion the LP was able to quickly give a desired product mix based on the resource constraints of the system. It provides a tool to make decisions on which resources to increase to further optimize the system. In general the LP pointed to several areas (NDI, TF-34 Compressor, Clean, TF-34 Mill, Metal Spray and Fuel Control work centers) where improvements should be looked for, and how much they would be worth. It is important to remember that the LP assumes that the constrained resources are kept busy continually.

Satisfying feasibility is only a rough cut at planning, ensuring that the number of units to be processed is not greater than the amount of time (on average) it takes to process each unit. Likewise, to determine the product mix is to look at the big picture of what we should be doing. There is much the LP model does not take into account, such as waiting times caused by variation in processing times. The LP model assumes that each component is processed exactly in the average amount of processing time $\mathbf{t}_{ij}$. To lend appreciation to this strong assumption, Appendix J shows the variation in arrival rates and processing times for shops that process the T-56 turbine rotor.

What is needed is a tool that takes such variation into account to derive estimates of flow time and work-in-process. This will be especially important for work centers that are bottlenecks to the overall production of engines. The following section discusses a tool used to approximate such information.

B. MPX: A QUEUING SYSTEM ANALYSIS TOOL

MPX, developed by Network Dynamics Incorporated, uses a queuing network approach. MPX also assumes a minimum five percent idle time in machines to cover for maintenance. Because of its network type design it is suited to handle overhaul processes where the work center or group of work centers complete a given process on a part without outside help (processing operations) from other work centers. MPX interjects variability, into arrival rates of parts, and into processing time and set-up time. However, rather than duplicating the exact probability distributions inherent in a specific process, MPX assumes exponentially distributed interarrival and service times.

The exponential distribution has higher variation than many other distributions that would fit the data better. However, without accurate data on processing and arrival rates available, it would be difficult to accurately select a distribution (Appendix J was derived by talking to workers). The range, mean and median arrival and processing rates shown are only sample statistics of the actual population probability distributions. Replicating the variation associated with these statistics, would require more complex simulation.

In view of the fact that production schedules can change greatly from quarter to quarter, a large investment in pinpointing actual process probability distributions, affected by a specific schedule, is not warranted. For this reason using an approach provided by a queuing network not only offers advantages of speed, but also does not necessitate determining complex probability distributions. Thus, the construction of the queuing model is greatly simplified.

The way a queuing network calculates flow time and work-in-process can be seen without looking at the actual equations by looking at Little's Flow equation. Although simplistic in appearance, the same general concepts apply to the more complex equations used in a queuing network.

1. Little's Flow Equation

Little's formula [Ref. 13] shows how the variables L (average number of entities in the system or WIP), L_q (average number of entities in the queue), W (average time spent in the system), and W_q (average waiting time in the queue) are related to the arrival rate λ as shown below:

$$L = \lambda W$$

$$L_q = \lambda W_q$$

W and W_q are related according to equation (6), where μ is the average processing rate. When the time spent in the

$$W = W_q + \frac{1}{\mu} \tag{6}$$

system (W) is decreased, work-in-process (L) decreases. To decrease waiting time W_q, processing rates μ, can be increased or arrival rates λ, can be decreased.

For the system to be feasible on a continuous basis the processing rate μ, times the number of repair channels, must be greater than the arrival rate λ. In terms of time requirements this means that the time between arrivals must be more than the processing time.

MPX does not consider that a work center may be over capacity in a particular week because components requiring that resource were over inducted in that week. This type of precise planning requires further detail and is currently handled with computer programs called MRP II. However, where linear programming is a deterministic model, MPX takes into account the dynamics of the manufacturing environment:

> ...interactions between products, set-ups, machine failures, yield and rework, and late arrivals of raw materials. All these considerations impact lead times, work-in-process, and machine utilizations. [Ref. 14]

2. Focusing on Processing Constraints

MPX was used to check the lead time and the work-in-process for a work center identified as a constraint in the linear programming phase. Just as the Seven-M tools use the Affinity Diagram to promote expanded thinking on the issues and then the ID to identify causes of the key issue, so linear programming is an overall look at the constraints of production. Likewise, similar to the Tree diagram, MPX is a good tool to focus attention on the component parts of a bottleneck.

In order to measure the queuing effect of subrouted components MPX requires processing times broken down to the subroute level. The increased volume of data in the case of the powerplants divisions would be several hundred times more than that required by the LP. Thus, for this situation, with the current state of centralized data, MPX is better suited for focusing on a small definable group of work centers.

3. Analysis of the Metal Spray Work Center

The metal spray work center and its interaction with the machine shop was selected for analysis by MPX. The following additional data was collected for input into MPX:

- mean time between failures (MTBF) and mean time to repair (MTTR) of machines;
- set-up times required on machines;
- lot size;
- types of labor groups.

Appendix K shows the data input to MPX. Nineteen primary parts are processed by the work center. The operational routings for only two of these nineteen parts are shown. The processing times were broken down to the subroute level in the database and multiplied by quarterly requirements for component program parts. The engine program parts were multiplied by the induction occurrence factors to yield the projected number of components undergoing the operation for the quarter. The requirement of processing the scheduled number of components for the quarter could not be met initially, due to the high wire spray equipment failure rate.

At this point modifications were made to make the model feasible, in this first "what-if" case. The reliability of the metal spray equipment was increased from a MTTF of 60 hours to 70 hours, and the MTTR was decreased from 30 hours to 20 hours. With this improvement the problem became feasible to meet the end use demand specified for the quarter in the input data. The equipment utilization graphs in Appendix L show equipment utilization for the base case and the first and second what-if cases.

In the second what-if case the batch sizes are decreased from their historical levels, to a level in the direction needed to optimize the system as a whole, under TOC. The improvements to the wire spray machine which made the models production run feasible are continued in this case. The batch sizes are reduced as shown in Figure L-3 to a maximum of two parts per lot. The result was an infeasible production run. This what-if scenario showed that there is a physical barrier to decreasing batch sizes.

Additional what-if cases to check the effects of transfer batches and set-up time reductions were not done.

It should be noted that TOC does not attempt reduced batch sizes without reducing setups.[12] Hence this result should not be construed to mean that small batches are not an appropriate objective.

The results of decreasing batch sizes for the metal spray shop was to cause increased set-up time and the resulting queuing for the wire spray machine. The result is that greater than 95% of the machine time is required to meet the quarterly schedule, as shown in Figure 5-2.

Referring back to the first "what-if" case, Appendix M shows the resulting flow time and work-in-process projections for each part. The T3040-0 Case Assembly had the longest flow time at 19.5 days, due to the fact it is wire sprayed and machined several times.

It is possible the model errors on the side of over assigning parts to wire spray when they can possibly be processed on plasma or thermo. The best results would most likely be achieved by someone very familiar with the process, working right in the shop, so questions could be resolved on the spot. Being able to check flow times based

[12] TOC has a companion theory Just-In-Time (JIT) which is the source of this idea and stresses low inventory levels and movement of material on a pull basis rather than a push basis.

EQUIPMENT GROUP NAME	% of CAPACITY REQUIRED FOR SETUP	FOR RUN	WAIT FOR LABOR	EQUIP DOWN	TOTAL	
WIRE SPRAY	2.6	42.7	38.8	12.9	97.0	- over 95%
PLASMA	0.8	1.4	1.4	0.034	3.6	
OVEN	0.6	64.2	16.6	5.7	87.1	
BLAST	0.2	5.7	5.2	1.5	12.5	
THERMO	2.7	5.7	4.3	0.1	12.8	
DEGREASE	0.3	23.6	21.2	0.024	45.0	
BENCH	0.8	16.3	15.0	0.00017	32.1	
PRES CHK	0.047	0.2	0.3	0.000028	0.5	
MACH	0.9	5.2	0.0097	0.0060	6.1	

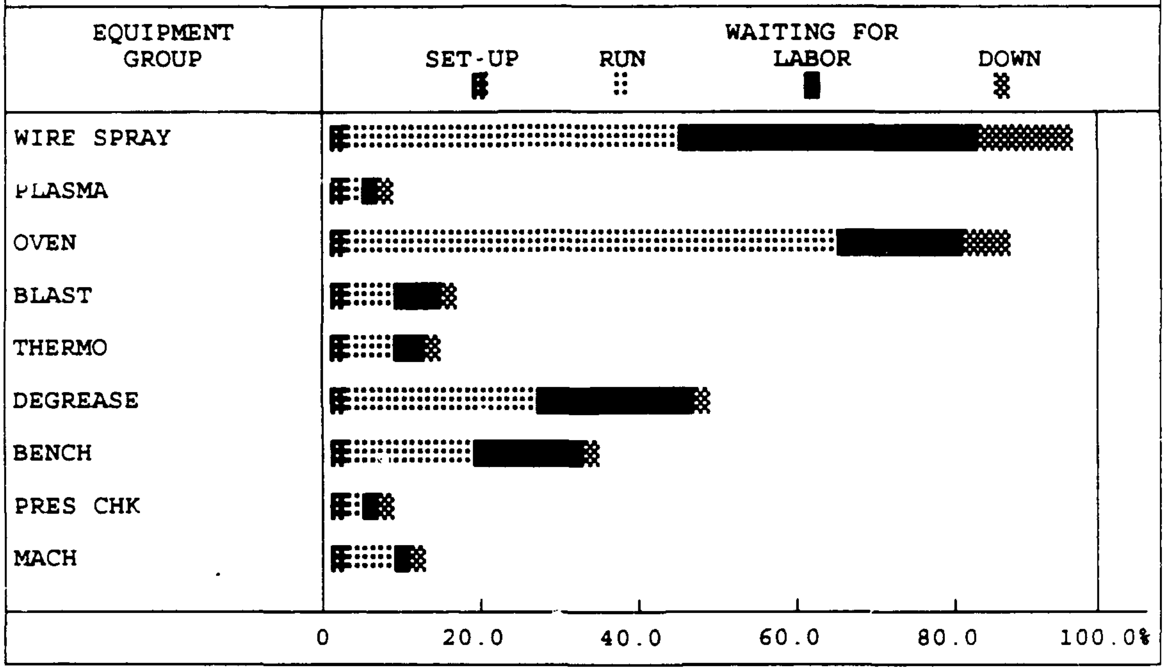

Figure 5-2. Equipment Utilization For Case #2 (Reduced Batch Sizes)

on the quarterly schedule, would allow feedback to planners on unacceptably long flow times.

C. CONCLUSIONS TO ANALYTICAL ANALYSIS

Linear programming would provide an ability to plan for which components to produce, in light of changing quarterly schedules. The labor constraints and, if added, processing constraints for the entire NADEP, could be quickly checked by activating and deactivating components scheduled (the LP variables)[13]. This provides the big picture answering the question: What products should we compete for?

Once the relative turbulence of downsizing and personnel cuts is passed, investment in tools such as queuing analysis would be warranted. Getting these analytical tools down to the level of key foremen or a system analyst for the entire division, would be an especially powerful addition to planning and validation of schedules.

Most NADEP planners and managers with a good understanding of TOC can intuitively find bottlenecks in their operations. The problem is, ithout an analytical way to predict bottlenecks, and how serious they are, planners cannot exploit the bottlenecks fully and they cannot quantify the value of improvements.

1. The Data Dilemma

The degree to which analytical methods can be successful is directly tied to the validity of the database the data is obtained from. Due to changes in shop numbers (reorganizations) over the last three years the database was very difficult to work with. Add to this, problems in

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[13] The STORM LP package had a feature in which a variable with its associated resource processing times could be omitted from the model without deleting the information.

transacting labor hours into the computer system and a political tendency[14] to over-document and the result is a database of lesser value. A sample of operations erroneously assigned to shops was taken from the T-56 compressor shop data. A four percent error rate in operations assigned to the compressor shop was estimated by the author by examining operation descriptions in the database. The Auditor General of the Navy has cited problems with the MDR databases among all NADEP's, in its 1985 audit of Depot repair reporting systems. [Ref. 15]

In spite of inaccuracies in the database two things should have been done differently for development of the LP model in this thesis. First, the data used for the components should be downloaded from the component program database by FIC-IIC code vice MDRCC-CIN. This will allow planners to identify components directly without matching part number or nomenclature. Secondly, only one year worth of data would be considered in order to avoid duplicate shop numbers from past reorganizations and to obtain data representative of the latest process improvements.

In the future, queuing network tools such as MPX may provide a way for planners to verify that resources with low

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[14] Under the threat of reduction in force (RIF) many workers are pressured to over document, to show 100% utilization of their time.

slack time, according to the LP analysis, can meet a proposed schedule. Once developed, a queuing network could be made available to foremen as part of a planning validation process. By training foremen to use such a tool for evaluating proposed schedules, they could validate their ability to meet those schedules. This will give them confidence to the plan and the ability to test out management directives to cut batch sizes. It will also give them a more objective way to identify process improvements in their work center that will pay the highest benefits. There are prerequisites to implementing such an idea which will be deal with in chapter VI.

D. RECOMMENDATIONS TO IMPROVE MDR DATABASE

The following corrections and additions to the MDR database would prepare the database for future analysis by linear programming and queuing analysis. Two prerequisites to improve the database include: First training workers on the importance of accurate time data. Secondly, establish a control to ensure the database is updated for the year, with an update query, when a shop number is changed. However, creating incentives to maintain an accurate database and improving the processes of transacting time into the MDR database is the real solution. The process of documenting time expended needs to be made easy to use and reliable.

The best recommendation on improving the database is illustrated in the example of the TF-34 turbine shop foreman. His belief is that he as a foreman is responsible for accurate entering of time transactions. As a result he has his workers enter their labor times on a portable transactor computer (like a hand-held calculator). Near the end of his shift he reviews and then downloads this data into the NADEP computer system personally.

1. Decentralized Databases

If shop foremen were able to maintain their own database via the current PC network available to them the records could be cleaned up and additional information could be tracked at the work center level. One of the most effective motivators in the public sector for quality is self interest and ownership of a responsibility. Once the foremen own their own databases and know what they can use that information for, there will be an incentive to keep the data accurate.

Added information which would be helpful to process improvement and future linear programming and queuing network analysis would include:

- Tracking which machine is used to process the part for a given operation.
- Recording set-up time.
- Processing times where different than labor times (i.e. for cleaning, heat treating and plating

operations) would allow development of better constraint equation data for future planning.

- Keeping track of mean time between failure (MTBF) and mean time to repair (MTTR) would help integrate and analyze equipment preventive maintenance needs.

- Standard part names for the first word used in the nomenclature and operation description fields to categorize similar parts and operations.

Training shop foremen in using a relational database, such as MicroSoft Access, would give them the tool necessary to collect processing time information. The ability to add pictures of the parts to such a database would also greatly aid in training and communication.

VI. REINVENTING THE SYSTEM

The goal of this chapter is to recommend solutions to problems uncovered by the Seven-M tools that cannot be solved effectively by working within the current system the NADEP operates under. This chapter will raise questions and point to areas for further research in improving the NADEP's underlying systems. From a TQL perspective redesign of systems should seek to eliminate waste and reduce complexity, two of the most important TQL guiding principles.

Although limited in scope, the examples provided throughout the thesis (such as the compressor blade beneficial suggestion and the blast operator's routing correction) seem to suggest fundamental flaws in our incentive programs and problems with communication. The blast operator example in Chapter II, Section A.1. further suggests there is a perception in civil service of maintaining the status quo.

A. CORRECTIONS TO PROBLEMS OUTSIDE THE CURRENT SYSTEM

The following specific problems, identified earlier with the Seven-M tools (Figure 3-3) could be solved by reinventing the system. The best solutions to these problems may be outside the boundaries of current system mandates.

Problems: "Improve production engineering support" and "Difficult to verify better ideas on methods and tooling."

Possible Solution: Make it easy for managers to contract for services outside the civil service system. This institutes competition and gives NADEP's access to core competencies not inherent to their organization. As an example, an upper level NADEP manager should be able to contract with the original manufacturer for research of engineering change proposals, or verification of time saving ideas concerning methods and tooling.

Problem: Organization is having communication problems (see Chapter II Sec A.1. and Chapter III Sec C.1.).

Possible Solution: Allow managers the ability to purchase plant property for items that can create efficiencies and aid communication in their division. To try and give examples of this is difficult to do, but, better phone systems, answering machines, and other communication systems come to mind. Budget line items not under a division heads authority make these types of purchases time consuming and difficult.

Problem: "Foremen are overtasked with too many collateral duties."

Possible Solution: Reduce the number of collateral duty programs and non-value added responsibilities supervisors and managers must comply with. Until performance evaluations can be completely done away with as Deming has told us for the past ten years, simplification will have to suffice. Make the process of writing evaluations both simple and concise, with as little clerical support as possible required. Reducing the time supervisors and managers must spend on this function in half will save thousands of man-hrs per year Navy wide. Most people spoken to on the subject of performance evaluations at the powerplants division saw the current evaluation system as a joke. Performance evaluations can also have a distortional effect as cited in Chapter IV under batching.

B. CORE COMPETENCE

In considering strategy formulation for improving the NADEP's underlying systems one of the key concepts to focus on is that of core competency. Core competencies can best be defined with the following example.

In the late 1950's and early 1960's Honda corporation of Japan was developing core competencies in smooth-running lightweight engines through manufacturing of motorcycles. This was years before it entered the automotive industry. [Ref. 16] The core competencies they developed allowed them to produce world class automobiles in the 1970's and 1980's. Likewise, in order for NADEP's to be able to support national security needs in the future, with quality, timely products, at a minimal amount of waste, core competencies must continue to be improved upon.

The danger in the current course of base closure decisions is to undermine the core competencies NADEP's possess and are continually improving upon. The ability and time required to regenerate complex overhaul processes needs to be considered carefully. Closing such facilities during interwar periods destroys the constancy of purpose required to continue improving overhaul processes needed to keep up with aging aircraft.

C. SHARING IDEAS

The decision to close three of the six NADEP's is out of their own hands, but there are issues that could improve their systems within their control. In order to improve their systems the NADEP's should take advantage of their common mission. In addition to competing against each other and the private sector they should share ideas. Currently, there is no incentive to share ideas, in fact there is an air of confidentiality over improvements and business practices, out of fear of being beat out by the competition. One proposal is to have an annual innovative improvements competition where each NADEP would pit their best ideas against those of the other NADEP's. The purpose would be to encourage counterparts in management to share process improvements, new planning tools, better methods, tooling and other innovative improvements.

D. CONTINUING EDUCATION AND TRAINING

In order to implement planning tools such as linear programming, planners will need to be educated/trained. Currently, planners are selected from personnel who have performed well out on the shop floor or other support areas. While this ensures they have working knowledge of the system, they will also need specialized training. The same is true of foremen. Giving key foremen the training required to understand and work with queuing network models of their production systems, could provide strategic advantages to pursuing process improvements. However, this would be based on being able to give them adequate training to understand the underlying assumptions, such as training in statistics.

An idea proposed here is a closer affiliation and networking with educational institutions. For example, NASA Aims Research Center uses a video link between classrooms at Stanford University and classrooms set-up on its own facility. Employees are able to ask questions and receive feedback via this video link. NADEP's could likewise offer training to qualified individuals in areas of management, operations research, industrial engineering, statistics and other subjects related to analyzing systems. This could tie into job rotation and furlough education opportunities for up and coming workers with management potential. By providing these benefits to participants on their own time, people who valued the training most would participate.

E. REFORMS TO CIVIL SERVICE

Reformers might want to draw lessons from an experiment at the Navy's China Lake facility in California - the Model Installation Program. Under this program complexity was removed from the civil service system and spending categories were made more flexible.[Ref. 17]
Despite the curtailment of this specific program due to costs, further research should be given its approach. In general there needs to be a standing avenue to request exemption from regulations that can be demonstrated to produce overall harm to a local system.

F. CHAPTER SUMMARY

To sum up this chapter, there are five points Osborne and Gaebler list concerning what they term mission driven governments, that summarize the general purpose of recommendations made in this chapter. They are:

- Give every employee incentive to save money.
- Free up resources to test new ideas.
- Give managers the autonomy they need to respond to changing circumstances.
- Create a predictable environment.

- Simplify the budget process.

There are numerous areas for further study, raised but unquantified, in the possible solutions given in this chapter. Looking at the big picture of the public sector rules, accounting schemes, civil service system, and budget authorization rules, and then focusing on the issues that are the greatest cause of complexity and waste is much needed.

VII. SUMMARY AND RECOMMENDATIONS

The purpose of this final chapter is to provide overall recommendations to the NADEP's as a group, from ideas generated throughout the entire scope of this thesis - from the case history, Seven-M tool, and analytical evaluation.

A. SUMMARY

The goal of this thesis was to determine the benefits of a TQL/systems approach to analyze problems in a production system. An approach was taken which looked at the overall system first, then focused in on specific problem areas. The case history took an overall look at many human factors in the system. The Seven-M tools used employee knowledge to produce leads for identifying constraints of various types. The general approach was to expand the group's thinking to the whole system, identify the major causes of constraints, and then focus thought on them. The Theory of Constraints was the guiding theory used to analyze the system. Deming recommends following a guiding theory and applying knowledge (*profound knowledge*) from other disciplines (such as psychology and management) to evaluate human/technological systems. As such, the force field diagram evaluated human elements affecting an important issue - batch sizes.

Chapter V continued the approach of viewing the whole system first and then the problem areas in that system. The degree to which the analytical methods applied were accurate for the specific case at Alameda was reduced by factors cited with the database. However, the method of evaluating the big picture and then the problem areas is a logical approach to working with large volumes of information in an effective manner. Finally, issues outside the bounds of the current NADEP system were introduced as potential areas for further research.

B. RECOMMENDATIONS

1. Process Improvements

There are many recommendations generated on the tree diagrams which would improve productivity and improve quality. Again the most important of those is improving the MDR tracking documents. One simple recommendation that could help ensure engine parts are processed to the assembly point without being trapped behind component program parts would be to color-code the tracking documents differently for the two programs. The engine program parts would be given a higher priority than the component program parts. This will allow both a reduction in lead time for engines and time savings for bottleneck shops in processing component program parts in batches.

2. Implementation

With respect to the tools used to evaluate productivity, resource constraints, product mix, lead time and work-in-process the following recommendations are made. Before any serious effort is put into using computer-aided analytical tools, process improvements to technical documentation and generation of an accurate and expanded MDR database is necessary. With this accomplished the ability to plan for resource constraints from quarter to quarter should be pursued using linear programming.

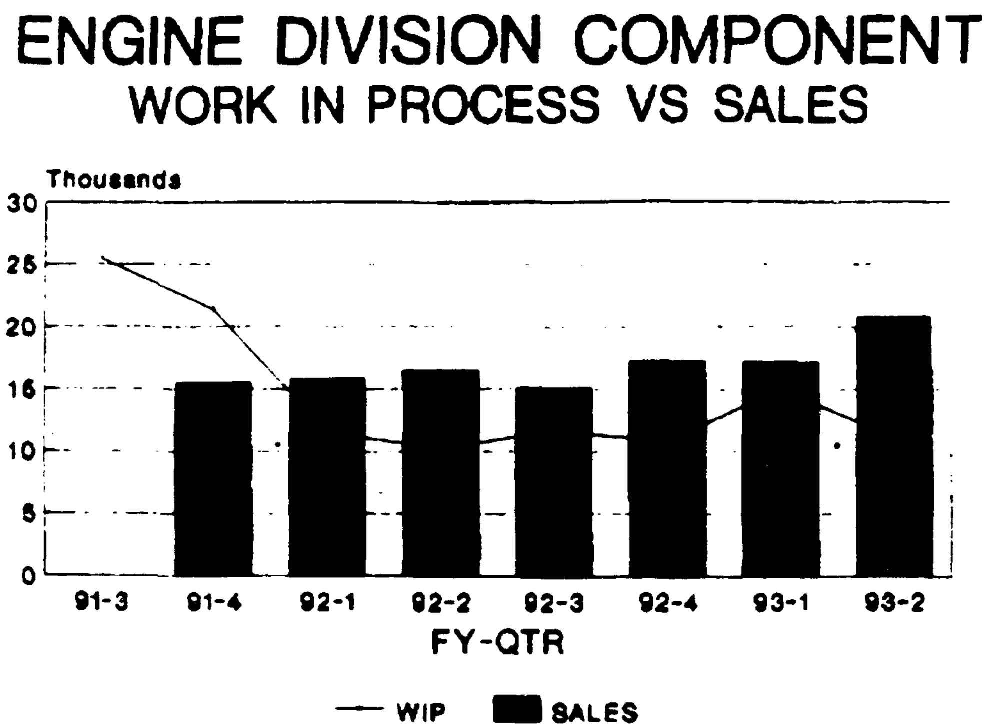
The most important thing to be done prior to spending money and time on queuing network systems would be to reduce the frustration levels many workers have, as discussed in the case history. Analytical efforts are only effective if process improvements to eliminate the causes of human frustration, material shortages, and information shortages are taking place.

Finally, perhaps in several years, with prerequisites in place, a queuing network program could help empower foremen to analyze production changes and process improvement ideas at their level. Such a program could be set up by a systems analyst for the entire division, but made available for foremen to use over the PC network currently in place. One of the greatest benefits to employing such a program would be the incentives it would produce to gain the foreman's interest in maintaining an accurate database.

Concurrent with these efforts, top management (i.e., Naval Aviation Depot Operations Center Commanding Officer, NADEP Commanding Officer, and top civil service managers) needs to be involved in pushing for changes to the system up the chain of command, in the media, with the Civil Service Commission, and congressional representatives. Reducing rules and regulations that tie the hands of managers and instead giving them the autonomy they need to respond to changing situations, will allow managers to further improve profits and quality.

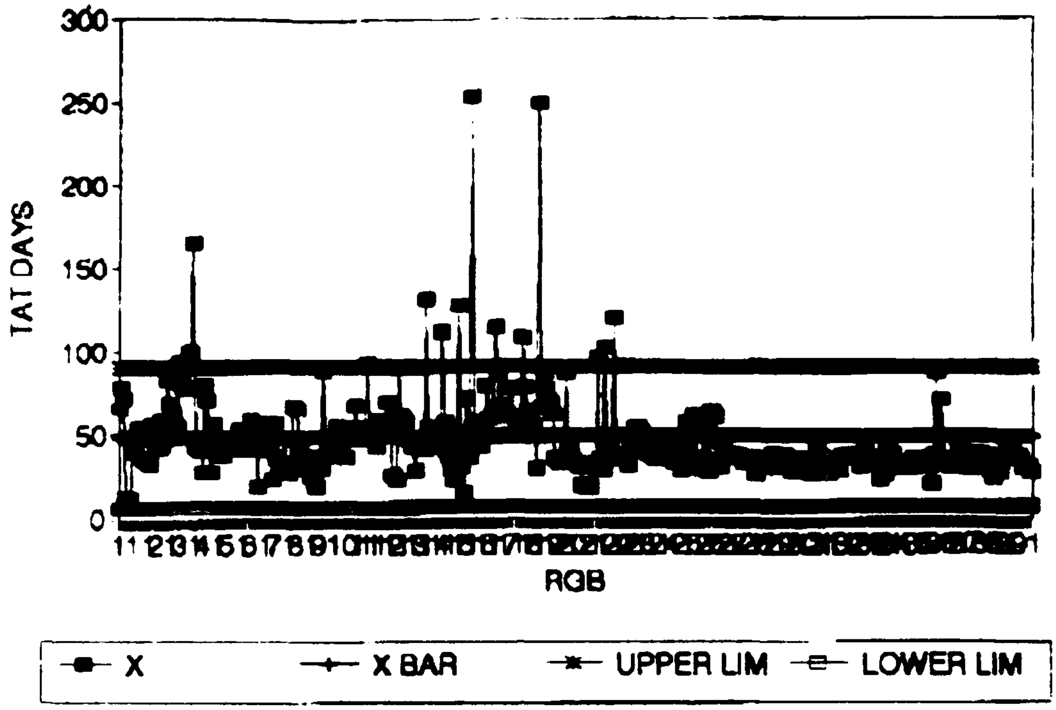
APPENDIX A: POWERPLANTS DIVISION PRODUCTION TRENDS

The following statistics show the significant progress the division has made over the last several quarters. The case points out problem areas primarily to lend balance and realism to the thesis. The results seem to show that even with underlying inefficiencies inherent in the system, process improvements can make a significant difference.



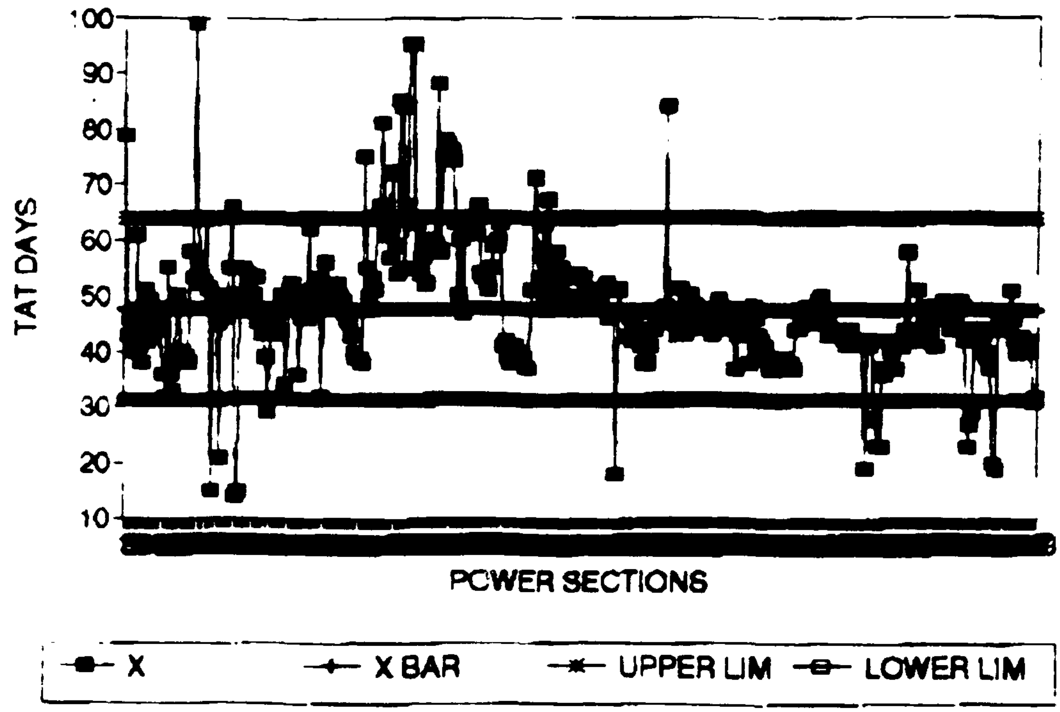
REDUCTION GEAR BOX

TAT 1/91-3/93

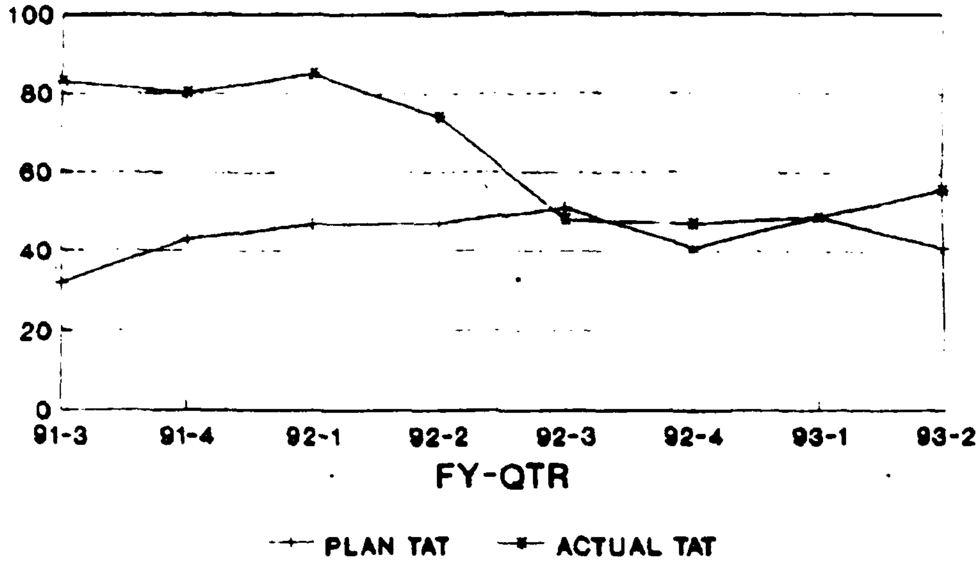


POWER SECTION

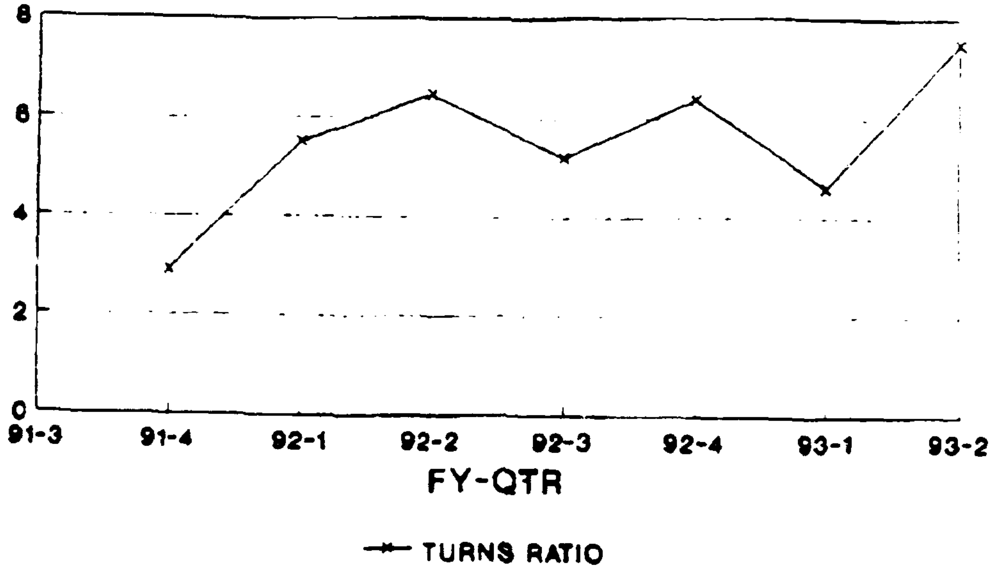
TAT 1/91-4/93



ENGINE DIVISION COMPONENT
TURN AROUND TIME



ENGINE DIVISION COMPONENT
TURNS RATIO



TR-SALES-4/WIP

APPENDIX B: SURVEYED OPINIONS ON PROCESS IMPROVEMENTS

The following statements are excerpts from a survey given to the group that constructed the Affinity diagram and ID prior to the group meeting. The questions and answers speak to some basic problem areas and potential solutions as understood before the use of the Seven-M tools. Conversations with other workers on the same questions have been added.

QUESTION: What is the most significant problem faced at the assembly point for the T-56/TF-34 engine:

Richard: "Having the proper serviceable parts available at the proper time so that engine assembly can be accomplished uninterrupted and in proper sequence."

Kathy: "[We are] not receiving parts from the supply system in a timely manner."

Richard: "[We have] long lead time and reliability problems with ordering new replacement parts."

Don: "The pre-expend bins being out of material."

QUESTION: Define when the problem is and when it is not:

Kathy: "This has been a constant problem when dealing with reworked parts that must go through the process shops. The only time it's not a problem is when we use all new parts and the supply system has them. The problem is all over the plant. I can't think of one place that it's not."

QUESTION: What is one of the key issues hurting productivity in your opinion:

Don: "Material costs in the past 10 years have quadrupled and the Aviation Supply Office budget has diminished severely during this same time frame. Material has not been procured is a timely manner.... All engines in the fleet are getting many hours accumulated and more and more parts are wearing out each time an engine comes through this Depot."

Ted: "General Foreman and other supervisors who don't understand the system and who manage by authoritative decree hurt the overall system. People are unwilling to admit they need help if they are responded to in a harsh manner. As a result, supervisors would just tell Mr X at meetings that things were fine in their work area."

Anonymous: "Frustration with publications, supervision by the whip, inadequate equipment, untimely solutions to problems, and lack of personal concern, lead to poor employee attitudes."

Anonymous: "A lot of people around here are basically lazy."

QUESTION: WHAT DO YOU SEE AS A SOLUTION TO IMPROVING WORK AND PART FLOW (THROUGHPUT):

Ted: "If we got rid of the forklifts in some or all areas of the building and got the controllers to move parts to the next shop by hand with the floor jacks we would cut the waiting time down drastically. I believe that Cleaning, Blasting and NDI are three of your constraint resources."

QUESTION: WHAT OTHER ISSUES DO YOU THINK HURT PRODUCTIVITY:

Paul: "When I came to work here, I was under an apprenticeship program. That was the best type of training you can get. The training methods now aren't very good. The new people being hired don't have an aircraft maintenance background and don't get trained very well."

Kathy: "Poor planning of the engine or component schedule that the shops produce can have a major impact."

APPENDIX C: SAMPLE COMPONENT TRACKING DOCUMENT (MDR)

JN 2560303 QA 692 MS 690

PRI 3 MO78 MIL STRIP ----

LINE NO	PART NAME	RELATED DESCRIPTION	CAGE	MDR CNTL CD	COMPONENT IDENTITY NO	PAGE
W136962	CASE ASSEM	BLY, UPPER LOWER CMPRSR		21441	304000000001	----

PRODUCT STD	CL	DISP	TMS NAME	SEQ NO	INDUCTED FEDERAL STOCK NUMBER	MODIFIED FEDERAL STOCK NUMBER	QUANTITY
		R	T56A14	N039	7RH 2840-004295196-DQ		1

PROCURE COST	MODEL CODE	MANUFACTURER	PUBLICATIONS NUMBER	SPARES	DL NO
15690		6896906			110206

MIL STRIP S/N# 836

LINE NO	SHOP NO	GEO AREA	SHOP CAT	START DAY	COMP DAY	OPER CODE	OPERATION DESCRIPTION	LINE NO. LINK NO	CERTIFICATION VERIFICATION
01	96524	56	MX	077	093		CONTD FROM 304000000000		
02	~~96524~~ EE 6.3614	56	XX	093	094	V345	METALIZE DIA P C/W 01, 02		D
03	~~96524~~	56	CX	077	077		CP #1 NOTIFY QA 47400		D
04	~~96524~~ EE 673614	56	XX	095	095	V350	FINISH MACH DIA P C/W 01, 02		D
05	~~96522~~	66	CX	095	095		CP # 2 NOTIFY QA 47400		D
06	96522	66	XX	096	096	V355	MEASURE & ~~MACH~~ FRONT FLANGE FOR		A26931
			EX??				METAL SPRAY C/W 01, 02		
08	96522	66	CX	096	096		CP #3 NOTIFY QA 47400 A23348		
09	96522	66	XX	097	097	V360	MEASURE & ~~MACH~~ DIA O FOR		A26931
			EX??				METAL SPRAY C/W ~~01,~~ 02		
11	96522	66	CX	087	097		CP # 4 NOTIFY QA 47400 A23348		
12	96524	56	XX	098	099	V365	METALIZE BORE C/W 01, 02		A96X131
13	96524	56	CX	099	099		CP # 5 NOTIFY QA 47400		
14	EE 673614	56	XX	099	100	V370	METALIZE DIA O C/W 01, 02		D
15	EE 673614	56	XX	100	101	V375	METALIZE FRONT FLANGE & CLEAN		D
			EX??				C/W 01, 02		
17	96524	56	XX	101	102	V380	REMOVE SHIM, CORK & RETORQ		

4-31-93

LINE NO	PART NAME	UNIFORM DATA CLASS CODE STRUCTURE	COMPONENT IDENTITY NO	PAGE
W136962	CASE ASSEM	2560303-3-THNP	304000000C01	1-2

NADEPALA FORM 4710 (REV 5/90)

APPENDIX D: TOP 80% OF COMPONENT PROGRAM, 2ND QTR FY93

FIC	IIC	PART NAME	WKL STD HOURS	QTR REQMT	QTR LOAD DEMAND	MCRCC CIN ASSIGNED	MDR HOURS ASSIGNED
T-56							
TB26	TB26	ROTOR ASSY	105	78	8190.00	214413030	39.45
RV3A	EUW6	ROTOR ASSY	105	33	3465.00	214413030	39.45
C67A	D0F4	ROTOR ASSY	67.4	35	2359.00	214413030	39.45
HT4A	JP23	LINER ASSY	6.7	336	2251.20	214412030	0.48
QNBA	GVK7	ROTOR ASSY	46	45	2070.00	214412050	11.3
NN86	NN86	CASE ASSY,	85	22	1870.00	214413040	32.86
HC2A	NNK4	CASE ASSY,	94	16	1504.00	214412020	2.1
5DHA	D455	SUPPORT, T	16	70	1120.00	214412010	16.4
				SUBTOTAL	**22829.20**	**/ 81.57% OF TOTAL**	
EE3B	BK28	CONTAINER,	20	55	1100.00		
0QLA	SNX4	GEAR, SPUR	13.65	69	941.85		
PLTA	DQY8	DIFFUSER A	23.5	25	587.50		
EE3B	DSW2	CONTAINER	20	27	540.00		
6PV1	6PV1	CASING, TU	15.4	35	539.00		
EF52	EF52	HOUSING, C	25.4	17	431.80		
G7J2	G7J2	VANE ASSY,	12.6	34	428.40		
D9PA	DQY9	BRAKE ASSY	16.9	14	236.60		
BG31	BG31	CASE ASSY,	17.4	12	208.80		
QF09	QF09	LAB SEAL,	3.5	25	87.50	TOTAL	
AQE0	AQE0	SHAFT GEAR	14.25	4	57.00	27987.65	
TF-34							
APAB	6WG1	DISK ASSY	45	51	2295.00	225215010	12.13
L2X8	L2X8	MODULE HPT	76	27	2052.00	225212060	17.78
3B0A	K0R6	FRAME ASSY	53.6	30	1608.00	225213010	5.06
2YGA	LEC5	CONTROL	120	12	1440.00	225215130	28.84
L10A	PYW5	STATOR	127	10	1270.00	225213040	43.72
BDQA	JT50	LINER	41.5	30	1245.00	225212020	17.14
2LRA	KYY5	ROTOR ASSY	62	10	620.00	225212050	11.96
5L1A	K432	HOUSING	32.6	14	456.40	225212060	17.78
EEJA	P1R4	FRAME	6.8	65	442.00	225215040	0.58
BTFA	KVT9	GEARBOX	37.8	10	378.00	225211010	21.32
DP5A	L889	COVER, C-S	10.5	33	346.50	225212094	1.59
KKA9	KKA9	CONTAINER	16.5	18	297.00	22521CANO	5.68
				SUBTOTAL	**12449.90**	**/ 80.49% OF TOTAL**	
B86A	LBL7	NOZZLE	14.15	20	283.00		
NYQ8	NYQ8	LINER	11.5	23	264.50		
DAMA	PYW6	CASE	42.8	6	256.80		
CN1A	S962	FAN CASE	12.3	20	246.00		
GFCA	K3C6	PTO ASSY	12.26	20	245.20		
JXE7	JXE7	AIR SEAL	9.82	24	235.68		
51RA	K8M1	SUPPORT	15.5	15	232.50		
DP2A	P096	CASE,AXIA	12.6	12	151.20		
0R3A	NA04	SHAFT	7.4	17	125.80		

PIC	IIC	PART NAME	WKL STD HOURS	QTR REQMT	QTR LOAD DEMAND	MCRCC CIN ASSIGNED	MDR HOURS ASSIGNED
DQAA	LXP9	STATOR	28	4	112.00		
2W7A	K083	AMPLIFIER	18	6	108.00		
22VA	K5F8	SEAL, CARB	5.1	20	102.00		
P0S2	P0S2	CASING	5.4	15	81.00		
J4F0	J4F0	CONTAINER	4.95	16	79.20		
5MCA	KK52	SEAL&LINER	3.6	20	72.00		
J2P4	J2P4	CONTAINER	16.7	4	66.80		
CPQB	NMC1	CABLE CASE	8	6	48.00		
JT52	JT52	LINK ASSY	4	12	48.00		
JT53	JT53	LINK ASSY	4	12	48.00		
22TA	N214	SEAL	2.9	15	43.50		
4Q9A	K029	VALVE	3.4	12	40.80		
JXH0	JXH0	CASING	3.4	10	34.00		
51SA	JXF0	SEAL	5.1	6	30.60		
JSAA	N217	SEAL, CARB	2.5	12	30.00		
DFNA	JXD1	HOUSING	3.2	5	16.00		
56PA	K826	CASE, AFT FAN	2.2	4	8.80	TOTAL	
GFVA	P093	SEAL	1.32	6	7.92	15467.2	
AIR FORCE							
7NYW	7NYW	CONT ASSY	120	129	15480.00	225215130	28.84
7NHS	7NHS	MODULE HPT	98.2	90	8838.00	225212060	17.78
7NWC	7E76	STATOR	90	79	7110.00	225213040	43.72
7NBQ	7E55	ROTOR ASSY	115	53	6095.00	225213030	39.45
7NBV	7NBV	ROTOR ASSY	70	63	4410.00	225212050	11.96
7NCY	7NL4	BLADE SET	12.13	195	2365.35	225215010	12.13
				SUB TOTAL	**44298.35**	**/ 83.55%**	**OF TOTAL**
7NYT	7E15	STATOR	52	46	2392.00		
7NBT	7NLC	LINER	36.5	49	1788.50		
7NBH	7NBH	STATOR	35.13	33	1159.29		
7NHC	7NHC	SEAL	9.82	60	589.20		
7NCF	7E24	GEARBOX	25	20	500.00		
7NY0	7NY0	SUPPORT	4.75	60	285.00		
7NBX	7E52	PUMP	10.43	27	281.61		
7NCN	7D65	LINK ASSY	4.78	58	277.24		
7NCT	7E91	SEAL	2.5	90	225.00		
7NBR	7E50	PTO ASSY	12.22	17	207.74		
7CCF	7CCF	CASE FAN	9.25	22	203.50		
7NUU	7NUU	SEAL	6	22	132.00		
7NBG	7NBG	ACTUATOR	4	27	108.00		
7NBC	7NBC	SEAL ASSY	6.5	15	97.50		
7NCD	7E29	HOUSING	2.1	44	92.40		
7NC7	7NC6	HOUSING	9	10	90.00		
7NBN	7F81	SUPPORT	5.9	13	76.70		
7NFC	7D99	MOUNT	4	15	60.00		
7NCQ	7NCQ	FRAME	4.78	11	52.58		
7NC7	7NC7	HOUSING	15	3	45.00		
7NE9	7NE9	ACCUMULAT	3.08	10	30.80	TOTAL	
7NB3	7NB3	LINER	8.5	3	25.50	53017.91	

The top 80 percent of the second quarter component schedule grouped below by MDRCC CIN number result in the total load demads shown below:

SECOND QUARTER REQMT	TOTAL LOAD DEMAND	MDRCC CIN
70	1120	214412010
16	1504	214412020
336	2251	214412030
45	2070	214412050
146	14014	214413030
22	1870	214413040
10	378	225211010
30	1245	225212020
73	5030	225212050
131	11346	225212060
33	347	225212094
30	1608	225213010
53	6095	225213030
89	8380	225213040
834	5114	225215010
65	442	225215040
141	16920	225215130
18	297	22521CANO

APPENDIX E: TRIVIAL SHOPS DELETED FROM ANALYSIS

SHOP	MDRCC CIN	OPERATION DESCRIPTION	TIME
13300	2252120401000	PERFORM INDUCTION PROCEDURE	0.11
13400	2252120401000	PERFORM RETURN PROCEDURES	0.27
93331	2252151317000	WELD/REPAIR C/W 01 WP 235 00	0.05
93423	2252150602000	PAINT C/W 02	0.56
93434	2144130507000	NDT MAG C/W 01	0.06
93434	2144130514000	NDT MAGNA C/W 01	0.05
93545	2252151317000	TEST OIL SIDE C/W 01 WP 235 00	0.14
93545	2252151317000	TEST FUEL SIDE C/W 01 WP 235 00	0.13
94447	2144110501000	TEST C/W 01 & 02	0.03
94447	2144110501000	FINAL CHECK C/W 01	0.05
94447	2144110501000	DISASSEMBLE C/W 01	0.03
94447	2144150401000	ASSEMBLE C/W 01 & 02 PARA 7	0.05
94447	2144150401000	CLEAN C/W 02 PARA 3	0.03
94447	2144150401000	DISASSEMBLE C/W 02 PARA 2	0.04
94447	2144150401000	REWORK C/W 02 PARA 5	0.24
94447	2144150401000	EXAM C/W 01 PARA 2-25, 02, 03	0.06
96413	2144120633000	EXAM & EVAL C/W 01 ALL	0.03
96525	2252150603000	PAINT C/W 01 WP 331 00	0.06
96527	2154140201000	CHK FLG SURF F-G-H SQRE WITHIN	0.56
96527	2252130501000	TEST COUPONS C/W 01 WP 346	0.09
96629	2252151201000	FNL CK/TST/SFTY WR C/W 02&03&06	0.12
96646	2252151201000	DISASSEM C/W 02	0.04
96646	2252151201000	ASSEM C/W 02	0.07
96646	2252151201000	CLEAN C/W 01 & 05	0.05
96646	2252151201000	INSP/REPAIR C/W 02	0.06
		TOTAL HOURS DELETED:	2.97

APPENDIX F: STORM INPUT

LINEAR & INTEGER PROGRAMMING DATA SET

Problem Description Parameters

Title : NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

Number of variables	:	99
Number of constraints	:	27
Starting solution given	:	NO
Objective type (MAX/MIN)	:	MAX

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214410000	214410002	214411010	214411020	214411021
OBJ COEFF	7.15	113.1	5.9	6.39	1.74
PLATING	0.	0.	0.46	4.56	0.57
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	17.87	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	88.82	3.44	0.	0.
T56 MACH	0.	0.	0.24	0.08	0.02
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.92
E&E TF34	0.	6.11	0.	0.	0.
NDT	0.	0.	0.133779	0.981044	0.12263
WELD	7.15	0.	0.06	0.	0.
HEAT TREAT	0.	0.	0.	0.	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.	0.	0.23826	0.550976	0.074456
BLAST	0.	0.	0.1	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.	0.	0.87	0.	0.
TF34 MILL	0.	0.	0.36	0.31	0.04
METAL SPRA	0.	0.3	0.	0.	0.
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214411040	214411050	214412010	214412020	214412030
OBJ COEFF	23.95	19.05	19.	2.53	0.86
PLATING	4.86333	0.07	0.	0.	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.02	0.	0.
T56 MACH	0.37	4.43	0.27	0.	0.
T56 F/C	0.	1.	0.	0.	0.
BEARING	0.02	0.02	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.875675	0.050167	0.859751	0.232997	0.133779
WELD	0.	0.02	1.96	0.1	0.19
HEAT TREAT	0.	0.	1.10704	0.	0.18
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.480556	0.	1.30547	0.313543	0.193586
BLAST	0.05	0.	0.5155	0.165	0.065
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.37	0.04	6.22	0.83	0.07
TF34 MILL	0.61	0.	4.75	0.	0.02
METAL SPRA	0.12	0.	2.07	0.91	0.02
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	1.46	0.83	0.	0.	0.
FP ACC IGN	6.3	0.9	0.	0.	0.
F/C ACC IG	0.	11.63	0.	0.	0.
PUMPS CONT	8.5	0.06	0.	0.	0.
VARBL TYPE	OMIT	OMIT	POS	POS	POS
LOWR BOUND	.	.	10.	5.	70.
UPPR BOUND	.	.	70.	16.	336.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214412040	214412050	214412060	214412061	214412062
OBJ COEFF	3.73	16.53	1.25	1.05	2.92
PLATING	0.	0.	0.57	0.	2.55
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.45	4.15	0.	0.	0.
T56 POWER	0.4	0.	0.04	0.	0.
T56 MACH	0.1	0.08	0.25	0.	0.02
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.468225	2.50835	0.183946	0.07748	0.200668
WELD	0.04	0.05	0.05	0.3	0.
HEAT TREAT	0.72	0.36	0.	0.	0.
COMP TF34	0.	4.79	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.784273	2.96832	0.104239	0.036732	0.044674
BLAST	0.69	0.77	0.04	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.	0.04	0.	0.	0.02
TF34 MILL	0.	0.6	0.03	0.64	0.1
METAL SPRA	0.12	0.45	0.	0.	0.
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	POS	OMIT	OMIT	OMIT
LOWR BOUND	.	15.	.	.	.
UPPR BOUND	.	45.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214412063	214412080	214413010	214413020	214413030
OBJ COEFF	3.83	2.64	0.82	15.29	57.26
PLATING	1.84	0.	0.	0.29	8.7235
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.03	0.	0.	0.	0.
COMP T56	0.	0.	0.24	0.16	6.97
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.07	0.	0.03
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.43	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.066889	0.	0.083612	0.317724	8.94966
WELD	0.	0.	0.09	1.17	0.04
HEAT TREAT	0.09	0.	0.	0.09	0.
COMP TF34	0.	0.	0.	0.	20.09
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.059565	0.	0.208477	0.307752	5.21007
BLAST	0.	0.	0.095	0.375	1.8105
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.	0.	0.	3.41	2.32
TF34 MILL	1.32	0.	0.02	5.11	4.01
METAL SPRA	0.	0.	0.02	2.06	0.
TF34 MACH	0.	0.	0.	2.04	0.
E&E PNEUD	0.	0.07	0.	0.	0.
FP ACC IGN	0.	2.57	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	POS
LOWR BOUND	.	.	.	.	0.
UPPR BOUND	.	.	.	.	146.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214413040	214413050	214413051	214413052	214415020
OBJ COEFF	33.48	2.98	2.85	3.78	2.24
PLATING	0.525	1.28113	0.	1.37	0.57
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	6.93	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.92	0.	0.	0.19	0.11
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.5	0.53	0.77	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.083612	0.	0.	0.31215	0.12263
WELD	0.	0.	0.	0.02	0.
HEAT TREAT	0.	0.	0.	0.36	0.
COMP TF34	2.67	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.173731	0.	0.	0.446737	0.07942
BLAST	0.145	0.	0.	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	3.54	1.2	1.14	0.17	0.
TF34 MILL	8.06	0.	0.	0.13	0.86
METAL SPRA	10.44	0.	1.19	0.04	0.
TF34 MACH	0.	0.	0.	0.	0.51
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	POS	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	10.	.	.	.	.
UPPR BOUND	22.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	214415022	214415040	214415041	214415060	214415070
OBJ COEFF	2.39	7.93	1.39	2.25	1.66
PLATING	0.	0.	0.23	0.	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.12	0.08	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.174191	0.050167	0.	0.	0.
WELD	0.49	0.15	0.	0.	0.
HEAT TREAT	0.	0.	0.	0.	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.089968	0.029783	0.019855	0.	0.
BLAST	0.06	0.03	0.035	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	1.47	0.13	0.	0.	0.
TF34 MILL	0.	0.09	0.	0.	0.
METAL SPRA	0.02	0.	0.	0.	0.
TF34 MACH	0.	0.	0.42	0.	0.
E&E PNEUD	0.	0.37	0.08	0.12	0.07
FP ACC IGN	0.	5.72	0.	1.65	1.59
F/C ACC IG	0.	0.05	0.	0.48	0.
PUMPS CONT	0.	1.24	0.61	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

OBJ COEFF	49.02	41.07	16.66	2.92	1.18
PLATING	0.	1.50074	4.1	0.	0.57
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	9.85	0.04	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	39.02	0.	0.	0.	0.
T56 MACH	0.	4.61	0.4	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.	0.575158	0.4738	0.	0.183946
WELD	0.	2.25	0.	0.	0.
HEAT TREAT	0.	0.337425	0.09	0.	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.	1.74333	0.812671	0.	0.173731
BLAST	0.	0.512573	0.72	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.	7.63	0.14	1.	0.09
TF34 MILL	0.	17.67	7.45	0.	0.11
METAL SPRA	0.15	2.66	0.	0.	0.
TF34 MACH	0.	1.59	2.51	0.	0.07
E&E PNEUD	0.	0.	0.	0.28	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	1.63	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	215414051	215414052	215414060	215414070	215414071
OBJ COEFF	0.41	2.54	2.02	5.86	1.
PLATING	0.	0.64	0.64	1.5	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.02	0.	0.	0.
T56 MACH	0.	0.	0.	0.02	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.42	3.06	0.73
E&E TF34	0.	0.	0.	0.	0.
NDT	0.	0.21739	0.250836	0.886284	0.301002
WELD	0.	0.	0.	0.	0.
HEAT TREAT	0.	0.23	0.	0.	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.18	0.
CLEAN	0.049638	0.367317	0.248187	0.	0.
BLAST	0.	0.055	0.	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.36	0.	0.12	0.	0.
TF34 MILL	0.	1.03	0.02	0.21	0.
METAL SPRA	0.	0.	0.	0.	0.
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.35	0.09	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	215414080	215414081	215414090	215414091	215414092
OBJ COEFF	6.53	11.04	2.81	2.17	8.62
PLATING	2.25	5.65868	0.64	1.21	6.02
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.02	0.	0.	0.	0.
T56 POWER	0.	0.27	1.79	0.04	0.
T56 MACH	0.95	0.65	0.	0.2	0.02
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.345595	0.328872	0.183946	0.12263	0.507244
WELD	0.	0.	0.	0.	0.
HEAT TREAT	0.	0.	0.	0.	0.27
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.411991	0.466592	0.173731	0.168768	0.719744
BLAST	0.15	0.62	0.	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	1.97	0.66	0.04	0.12	0.47
TF34 MILL	0.1	2.42	0.	0.32	0.67
METAL SPRA	0.02	0.	0.	0.	0.
TF34 MACH	0.35	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	215414093	215414094	215414095	215414100	215414106
OBJ COEFF	12.69	2.45	1.97	3.72	3.54
PLATING	7.86	0.49	0.	2.44	2.42
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.02	0.
T56 MACH	0.78	0.	0.04	0.	0.15
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.	0.	0.	0.	0.
NDT	0.746931	0.355103	0.	0.462652	0.195094
WELD	0.	0.	0.	0.02	0.
HEAT TREAT	0.09	0.	0.	0.09	0.18
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.8619	0.679936	0.	0.426883	0.282934
BLAST	0.	0.	0.	0.09	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.37	0.	0.67	0.	0.02
TF34 MILL	1.38	0.95	0.	0.19	0.31
METAL SPRA	0.	0.	0.	0.02	0.
TF34 MACH	0.68	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	1.26	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	215414110	21541CAN0	225210002	225211010	225211030
OBJ COEFF	8.68	5.47	208.52	23.2	1.99
PLATING	0.5865	0.	0.	1.06	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.23	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	3.27	1.99
E&E TF34	0.	0.	20.18	0.02	0.
NDT	0.207991	0.	0.	0.494702	0.
WELD	0.02	5.47	0.	0.	0.
HEAT TREAT	0.	0.	0.	0.36	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.439337	0.	0.	0.813434	0.
BLAST	0.	0.	0.	0.	0.
TF34 ASSY	0.	0.	187.92	8.8	0.
TF34 LATHE	1.94	0.	0.	3.08	0.
TF34 MILL	0.23	0.	0.	5.23	0.
METAL SPRA	0.	0.	0.42	0.12	0.
TF34 MACH	0.09	0.	0.	0.	0.
E&E PNEUD	1.21	0.	0.	0.	0.
FP ACC IGN	0.49	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	3.27	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	POS	OMIT
LOWR BOUND	.	.	.	3.	.
UPPR BOUND	.	.	.	10.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225211031	225211040	225211060	225212010	225212020
OBJ COEFF	2.	0.81	5.51	28.25	20.92
PLATING	0.	0.	0.9825	0.71	2.84
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.15	0.	0.	0.
BEARING	2.	0.	0.29	0.	0.
E&E TF34	0.	0.	0.	0.24	0.42
NDT	0.	0.	0.066889	9.03397	0.656352
WELD	0.	0.	0.	0.45	7.05
HEAT TREAT	0.	0.	0.	0.18	0.259583
COMP TF34	0.	0.	0.	1.39	0.
TURB TF34	0.	0.	0.	9.78	0.
CLEAN	0.	0.223369	0.138985	2.6705	1.17343
BLAST	0.	0.	0.	0.05	0.13625
TF34 ASSY	0.	0.05	4.04	0.	0.88
TF34 LATHE	0.	0.	0.	3.78	1.16
TF34 MILL	0.	0.	0.	0.04	2.68
METAL SPRA	0.	0.15	0.	0.84	3.73
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.24	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	POS
LOWR BOUND	.	.	.	.	15.
UPPR BOUND	.	.	.	.	30.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225212030	225212040	225212050	225212060	225212080
OBJ COEFF	7.46	24.68	17.35	21.	13.28
PLATING	0.	0.	0.42	2.61075	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.02	2.82	0.	0.	0.02
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0	0.	0.	0.
E&E TF34	0.3	0.06	0.2	0.16	0.08
NLT	0.56856	2.12165	4.29966	0.401336	0.139352
WELD	1.79	3.29	0.	0.53	1.08
HEAT TREAT	0.06	0.	0.	0.2	0.
COMP TF34	0.	5.96	2.32	0.	0.02
TURB TF34	0.	0.04	7.64	0.02	0.
CLEAN	0.948076	0.955368	1.97743	0.475279	0.173111
BLAST	0.03	0.06	0.415	0.	0.070625
TF34 ASSY	0.02	0.	0.	2.05	0.03
TF34 LATHE	1.5	1.78	0.33	2.06	0.
TF34 MILL	1.31	5.92	0.06	11.07	11.68
METAL SPRA	0.96	0.	0.12	1.46	0.
TF34 MACH	0.	1.88	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	POS	POS	OMIT
LOWR BOUND	.	.	40.	1.	.
UPPR BOUND	.	.	73.	131.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225212081	225212082	225212091	225212093	225212094
OBJ COEFF	4.99	1.01	3.22	1.15	1.61
PLATING	0.	0.	0.699	0.57	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.97	0.76	0.	0.
E&E TF34	0.06	0.04	0.06	0.07	0.02
NDT	0.066889	0.	0.220735	0.200668	0.
WELD	0.	0.	0.	0.	0.11
HEAT TREAT	0.	0.	0.1095	0.06	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.02	0.	0.	0.	0.06
CLEAN	0.258035	0.	0.279459	0.15884	0.07942
BLAST	0.	0.	0.034	0.06	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	1.52	0.	0.	0.	0.23
TF34 MILL	0.08	0.	0.11	0.06	0.
METAL SPRA	2.99	0.	0.95	0.	0.99
TF34 MACH	0.	0.	0.	0.	0.1
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.02	0.	0.02
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	POS
LOWR BOUND	.	.	.	.	15.
UPPR BOUND	.	.	.	.	33.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225212095	225212096	225213010	225213020	225213021
OBJ COEFF	1.33	0.96	5.82	8.66	1.16
PLATING	0.71	0.49	0.23	3.4243	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.67	0.
E&E TF34	0.04	0.04	0.25	0.06	0.02
NDT	0.133779	0.133779	0.588069	0.317724	0.
WELD	0.	0.	0.28	0.	0.
HEAT TREAT	0.09	0.09	0.11875	0.09	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.04	0.	0.	0.06	0.
CLEAN	0.11913	0.11913	0.522228	0.561208	0.059565
BLAST	0.06	0.06	0.212917	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.02	0.	0.61	0.49	0.
TF34 MILL	0.06	0.04	2.05	1.99	0.06
METAL SPRA	0.06	0.	0.36	0.9	1.
TF34 MACH	0.	0.	0.66	0.11	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.02	0.02
VARBL TYPE	OMIT	OMIT	POS	OMIT	OMIT
LOWR BOUND	.	.	1.	.	.
UPPR BOUND	.	.	30.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225213030	225213040	225213050	225213065	225213066
OBJ COEFF	54.72	44.11	14.16	2.02	2.07
PLATING	2.69	0.39125	1.08875	0.	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	1.96	0.22	0.29	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.08	0.	0.06	0.	0.
NDT	8.75136	0.107923	0.635449	0.066889	0.066889
WELD	0.11	0.	0.11	0.	0.
HEAT TREAT	0.27	0.	0.	0.	0.
COMP TF34	27.24	22.46	1.85	1.34	1.93
TURB TF34	0.1	0.	0.07	0.	0.
CLEAN	3.48952	0.19855	0.990268	0.07942	0.07942
BLAST	0.42	0.	0.265	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	3.11	0.	0.65	0.54	0.
TF34 MILL	2.74	14.82	6.19	0.	0.
METAL SPRA	4.35	5.92	1.43	0.	0.
TF34 MACH	0.29	0.	0.59	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	POS	POS	OMIT	OMIT	OMIT
LOWR BOUND	1.	1.	.	.	.
UPPR BOUND	53.	89.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	BLADE SET	225215022	225215030	225215040	225215050
OBJ COEFF	0.92	1.27	1.85	0.58	2.17
PLATING	0.	0.	0.	0.	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.25	0.2	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.56	0.	0.	0.
E&E TF34	0.	0.07	0.	0.04	0.1
NDT	0.078038	0.314416	0.	0.	0.117056
WELD	0.	0.	0.	0.04	0.61
HEAT TREAT	0.	0.	0.	0.	0.
COMP TF34	0.4	0.02	0.	0.	0.
TURB TF34	0.	0.02	0.	0.	0.04
CLEAN	0.099275	0.11913	0.	0.	0.07942
BLAST	0.	0.	0.	0.	0.
TF34 ASSY	0.	0.	0.	0.	0.
TF34 LATHE	0.	0.	0.	0.	0.
TF34 MILL	0.1	0.	0.	0.	0.
METAL SPRA	0.	0.	1.85	0.5	1.23
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	POS	OMIT	OMIT	POS	OMIT
LOWR BOUND	80.	.	.	35.	.
UPPR BOUND	843.	.	.	65.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225215060	225215070	225215080	225215081	225215100
OBJ COEFF	24.84	1.77	3.04	3.41	0.65
PLATING	0.27625	0.	0.	0.	0.
FIBER GLAS	22.14	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	0.	0.
NAV COMP	0.	0.	0.	0.	0.
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.
T56 F/C	0.	0.	0.	0.	0.
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.52	0.05	0.	0.1	0.04
NDT	0.14214	0.066889	0.	0.267557	0.
WELD	0.02	0.	0.	0.	0.
HEAT TREAT	0.10625	0.	0.	0.	0.
COMP TF34	0.	0.	0.	0.02	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.880859	0.178695	0.554699	0.47652	0.019855
BLAST	0.131563	0.	0.	0.	0.
TF34 ASSY	0.	0.02	0.	0.	0.59
TF34 LATHE	0.	0.	0.	1.74	0.
TF34 MILL	0.14	0.	0.	0.	0.
METAL SPRA	0.48	1.46	2.48	0.83	0.
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	0.	0.	0.	0.	0.
FP ACC IGN	0.	0.	0.	0.	0.
F/C ACC IG	0.	0.	0.	0.	0.
PUMPS CONT	0.	0.	0.	0.	0.
VARBL TYPE	OMIT	OMIT	OMIT	OMIT	OMIT
LOWR BOUND	.	.	.	.	.
UPPR BOUND	.	.	.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225215120	225215121	225215130	225215131	225215140
OBJ COEFF	9.72	2.49	28.92	5.4	2.34
PLATING	0.23	1.32	0.	1.14	0.
FIBER GLAS	0.	0.	0.	0.	0.
INFLT REFU	0.	0.	0.	1.37	0.
NAV COMP	0.	0.	0.	0.	1.67
E&E T56	0.	0.	0.	0.	0.
COMP T56	0.	0.	0.	0.	0.
T56 POWER	0.	0.	0.	0.	0.
T56 MACH	0.	0.	0.	0.	0.04
T56 F/C	0.	0.	0.	0.	0.02
BEARING	0.	0.	0.	0.	0.
E&E TF34	0.04	0.	0.04	0.06	0.
NDT	0.25545	0.200668	0.087793	0.100334	0.
WELD	0.1	0.05	0.16	0.	0.14
HEAT TREAT	0.	0.09	0.	0.	0.
COMP TF34	0.	0.	0.	0.	0.
TURB TF34	0.	0.	0.	0.	0.
CLEAN	0.342499	0.670106	0.121198	0.07942	0.
BLAST	0.03	0.02	0.	0.	0.
TF34 ASSY	0.	0.	0.	0.2	0.
TF34 LATHE	0.15	0.02	0.9	0.02	0.
TF34 MILL	0.05	0.08	0.	0.	0.
METAL SPRA	0.	0.	0.	0.	0.
TF34 MACH	0.	0.	0.	0.	0.
E&E PNEUD	2.44	0.02	1.03	0.17	0.
FP ACC IGN	0.	0.	5.25	1.85	0.2
F/C ACC IG	0.06	0.	21.34	0.42	0.27
PUMPS CONT	6.05	0.04	0.	0.	0.
VARBL TYPE	OMIT	OMIT	POS	OMIT	OMIT
LOWR BOUND	.	.	0.	.	.
UPPR BOUND	.	.	141.	.	.
INIT SOLN	0.	0.	0.	0.	0.

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	225215150	22521CAN0	T-56	TF-34	CONST TYPE
OBJ COEFF	1.31	5.68	558.32	635.76	XXXX
PLATING	0.	0.	66.9989	21.8828	<=
FIBER GLAS	0.	0.	0.	22.14	<=
INFLT REFU	0.	0.	0.	1.37	<=
NAV COMP	0.	0.	0.	1.67	<=
E&E T56	0.	0.	27.79	0.	<=
COMP T56	0.	0.	18.91	5.59	<=
T56 POWER	0.	0.	133.89	0.	<=
T56 MACH	0.	0.	15.43	0.04	<=
T56 F/C	0.	0.	1.	0.17	<=
BEARING	0.	0.	7.39	10.51	<=
E&E TF34	0.	0.	6.11	23.64	<=
NDT	0.083612	0.	23.3336	36.9627	<=
WELD	0.05	3.71	19.63	19.68	<=
HEAT TREAT	0.	0.	4.19446	2.17408	<=
COMP TF34	0.	0.	27.54	64.64	<=
TURB TF34	0.	0.	0.18	26.25	<=
CLEAN	0.233296	0.	21.7471	20.8995	<=
BLAST	0.	0.	7.09357	2.43472	<=
TF34 ASSY	0.95	1.97	0.	207.52	<=
TF34 LATHE	0.	0.	37.45	24.56	<=
TF34 MILL	0.	0.	60.14	67.62	<=
METAL SPRA	0.	0.	20.6	36.53	<=
TF34 MACH	0.	0.	8.25	3.63	<=
E&E PNEUD	0.	0.	4.49	3.65	<=
FP ACC IGN	0.	0.	19.21	7.54	<=
F/C ACC IG	0.	0.	12.17	22.09	<=
PUMPS CONT	0.	0.	17.01	6.22	<=
VARBL TYPE	OMIT	POS	POS	POS	XXXX
LOWR BOUND	.	10.	4.	0.5	XXXX
UPPR BOUND	.	18.	5.	1.	XXXX
INIT SOLN	0.	0.	0.	0.	XXXX

STORM DATA SET LISTING

DETAILED PROBLEM DATA LISTING FOR

NADEP ALAMEDA POWERPLANTS DIV MAJOR PRODUCTS & RESOURCES

ROW LABEL	R H S	RANGE
OBJ COEFF	XXXX	XXXX
PLATING	1020.	.
FIBER GLAS	340.	.
INFLT REFU	306.	.
NAV COMP	306.	.
E&E T56	510.	.
COMP T56	612.	.
T56 POWER	884.	.
T56 MACH	884.	.
T56 F/C	204.	.
BEARING	306.	.
E&E TF34	374.	.
NDT	578.	.
WELD	476.	.
HEAT TREAT	136.	.
COMP TF34	612.	.
TURB TF34	578.	.
CLEAN	442.	.
BLAST	272.	.
TF34 ASSY	714.	.
TF34 LATHE	612.	.
TF34 MILL	714.	.
METAL SPRA	510.	.
TF34 MACH	442.	.
E&E PNEUD	170.	.
FP ACC IGN	646.	.
F/C ACC IG	714.	.
PUMPS CONT	442.	.
VARBL TYPE	XXXX	XXXX
LOWR BOUND	XXXX	XXXX
UPPR BOUND	XXXX	XXXX
INIT SOLN	XXXX	XXXX

APPENDIX G: LINEAR PROGRAMMING OUTPUT

The STORM output shown below contains the optimal amount (value column) of various products that should be produced to maximize the revenue. The lower bounds set for each product are shown in Appendix F. The reduced cost column shows the amount by which the objective function will increase or decrease if one more unit of this product is introduced to the current solution. The cost column, which is the coefficient C_i, represents the weekly labor hours toward the **i-th** product. These coefficients multiplied by the dollars/hour the NADEP charges its customers will approximate the revenue produced per component. The Objective Function Value indicates that the optimal product mix yields $7,893 hours of production per week.

OPTIMAL SOLUTION - DETAILED REPORT

	Variable	Value	Cost	Red. cost	Status
8	214412010	10.0000	19.0000	-2.4498	Lower bound
9	214412020	16.0000	2.5300	0.6761	Upper bound
10	214412030	196.2332	0.8600	0.0000	Basic
12	214412050	15.0000	16.5300	-1.0195	Lower bound
20	214413030	0.0000	57.2600	-0.0419	Lower bound
21	214413040	11.8127	33.4800	0.0000	Basic
54	225211010	10.0000	23.2000	3.4455	Upper bound
60	225212020	30.0000	20.9200	5.8911	Upper bound
63	225212050	67.0182	17.3500	0.0000	Basic
64	225212060	1.0000	21.0000	-17.0652	Lower bound
70	225212094	33.0000	1.6100	0.8536	Upper bound
73	225213010	1.0000	5.8200	-3.6295	Lower bound
76	225213030	1.6457	54.7200	0.0000	Basic
77	225213040	1.0000	44.1100	-16.8840	Lower bound
81	BLADE SET	208.7483	0.9200	0.0000	Basic
84	225215040	65.0000	0.5800	0.2844	Upper bound
93	225215130	29.5717	28.9200	0.0000	Basic
97	22521CANO	18.0000	5.6800	5.6800	Upper bound
98	T-56	5.0000	558.3200	216.3696	Upper bound
99	TF-34	1.0000	635.7600	195.6547	Upper bound

Objective Function Value = 7893.719

The binding constraints of the current production schedule are shown in bold below. The RHS values have been reduced by 84.4 percent from the 40 hour week norm to account for time not actually spent working. The slack column shows how much of that particular resource is not used per week. The shadow price shows the increase in objective function value if the right hand side of the binding constraint can be increased by one hour. For example, if one extra production hour is available in NDT, the number of additional hours of production will be increased by 2.7475.

	Constraint	Type	RHS	Slack	Shadow price
1	PLATING	<=	1020.0000	525.3145	0.0000
2	FIBER GLAS	<=	340.0000	317.8600	0.0000
3	INFLT REFU	<=	306.0000	304.6300	0.0000
4	NAV COMP	<=	306.0000	304.3300	0.0000
5	E&E T56	<=	510.0000	371.0500	0.0000
6	COMP T56	<=	612.0000	312.1155	0.0000
7	T56 POWER	<=	884.0000	214.3500	0.0000
8	T56 MACH	<=	884.0000	792.0423	0.0000
9	T56 F/C	<=	204.0000	198.8300	0.0000
10	BEARING	<=	306.0000	225.8400	0.0000
11	E&E TF34	<=	374.0000	288.6218	0.0000
12	**NDT**	<=	578.0000	0.0000	**2.7475**
13	WELD	<=	476.0000	8.7032	0.0000
14	HEAT TREAT	<=	136.0000	48.9107	0.0000
15	**COMP TF34**	<=	612.0000	0.0000	**0.4369**
16	TURB TF34	<=	578.0000	36.6663	0.0000
17	**CLEAN**	<=	442.0000	0.0000	**2.1554**
18	BLAST	<=	272.0000	167.4803	0.0000
19	TF34 ASSY	<=	714.0000	354.5700	0.0000
20	TF34 LATHE	<=	612.0000	138.8482	0.0000
21	**TF34 MILL**	<=	714.0000	0.0000	**3.1685**
22	**METAL SPRA**	<=	510.0000	0.0000	**0.5911**
23	TF34 MACH	<=	442.0000	392.6827	0.0000
24	E&E PNEUD	<=	170.0000	113.4412	0.0000
25	FP ACC IGN	<=	646.0000	387.1586	0.0000
26	**F/C ACC IG**	<=	714.0000	0.0000	**1.3317**
27	PUMPS CONT	<=	442.0000	350.0700	0.0000

Note: The resource levels of the LP model have not been decreased for products not considered by the LP. As a result shops such as fiber glass repair which work T-56 propellers and other components show large amounts of slack. This would have to be reduced in reality to properly represent the engine and component overhaul programs.

APPENDIX H: ANALYSIS OF CONSTRAINT RESOURCES

The following analysis shows how adding labor time to constrained resources can affect both which products are produced, the value of the objective function (total labor hours worked and resulting revenue), and the shadow price. Multiplying the change in the Objective function value by the dollar per hour amount the NADEP charges its customers will yield the revenue increase for the actions taken. A very rough estimate of labor charges to the customer is 75 $/hr. The following analysis shows the result of increasing the right hand side values of the constraint resources.

PARAMETRIC ANALYSIS OF RIGHT-HAND SIDE VALUE - NDT

COEF = 578.000 LWR LIMIT = 578.000 UPR LIMIT = Infinity

	Range From	Range To	Shadow Price	Variable Leave	Variable Enter
RHS	578.000	589.300	2.747	SLACK 16	214413030
Obj	7893.719	7924.765			
RHS	589.300	595.046	2.737	225213030	SLACK 16
Obj	7924.765	7940.492			
RHS	595.046	595.642	2.625	BLADE SET	214412010
Obj	7940.492	7942.058			
RHS	595.642	602.033	2.576	SLACK 16	SLACK 12
Obj	7942.058	7958.525			
RHS	602.033	Infinity	0.000	---- No change ----	
Obj	7958.525	7958.525			

Adding just 24 hours would alleviate the NDT constraint and increase revenue by $4,860 per week. The NDT shop has 17 personnel assigned.

$$75\$/hr \times (7,958.5 - 7,893.7) = \$4,860$$

The Clean shop has 13 people. Multiply this by one extra eight hour shift and the 84.4 percent worker availability factor gives a potential 87.75 of overtime per week.

PARAMETRIC ANALYSIS OF RIGHT-HAND SIDE VALUE - CLEAN

COEF = 442.000 LWR LIMIT = 442.000 UPR LIMIT = Infinity

	Range From	Range To	Shadow Price	Variable Leave	Variable Enter
RHS	442.000	447.820	2.155	SLACK 13	214412050
Obj	7893.719	7906.263			
RHS	447.820	461.185	1.533	225213030	225212020
Obj	7906.263	7926.746			
RHS	461.185	476.296	0.923	214412030	225215040
Obj	7926.746	7940.693			
RHS	476.296	486.061	0.866	BLADE SET	214412010
Obj	7940.693	7949.153			
RHS	486.061	488.645	0.477	225215040	SLACK 17
Obj	7949.153	7950.385			
RHS	488.645	Infinity	0.000	---- No change ----	
Obj	7950.385	7950.385			

Increasing cleaning shop overtime only 47 hours would alleviate this constraint. This increase from 442 to 489 hours would generate $4,275 in revenue per week. The analysis also shows the change of the product mix under the Leave and Enter columns. For the above analysis one more 214412050, 225212020, 225215040, and 214412010 would be produced and one less 225213030, 214412030, BLADE SET, and a 225215040 would be produced.

TF-34 Milling has 21 people. Multiply this by one extra eight hour shift and the 84.4 percent worker availability factor gives a potential of 141 hours of overtime per week.

PARAMETRIC ANALYSIS OF RIGHT-HAND SIDE VALUE - TF34 MILL

COEF = 714.000 LWR LIMIT = 714.000 UPR LIMIT = Infinity

	------- Range -------		Shadow	---- Variable ----	
	From	To	Price	Leave	Enter
RHS	714.000	717.724	3.168	225213030	214413030
Obj	7893.719	7905.518			
RHS	717.724	718.035	2.624	BLADE SET	214412010
Obj	7905.518	7906.335			
RHS	718.035	737.159	2.412	SLACK 13	BLADE SET
Obj	7906.335	7952.457			
RHS	737.159	754.775	2.410	214413040	225215040
Obj	7952.457	7994.916			
RHS	754.775	781.165	2.397	214412030	214413040
Obj	7994.916	8058.164			
RHS	781.165	784.429	2.372	225215040	214412020
Obj	8058.164	8065.905			
RHS	784.429	793.375	2.182	214412020	225212094
Obj	8065.905	8085.427			
RHS	793.375	794.878	2.062	214413030	225212020
Obj	8085.427	8088.527			
RHS	794.878	813.072	2.033	225212094	214413030
Obj	8088.527	8125.515			
RHS	813.072	831.447	1.912	SLACK 20	225212060
Obj	8125.515	8160.645			
RHS	831.447	1058.385	1.374	214413040	SLACK 13
Obj	8160.645	8472.464			
RHS	1058.385	1401.849	1.222	214413030	214412030
Obj	8472.464	8892.276			
RHS	1401.849	1551.449	1.219	225212020	214413030
Obj	8892.276	9074.697			
RHS	1551.449	1591.346	1.187	214412010	TF-34
Obj	9074.697	9122.066			
RHS	1591.346	1692.733	0.381	214412030	SLACK 21
Obj	9122.066	9160.741			
RHS	1692.733	Infinity	0.000	---- No change	----
Obj	9160.741	9160.741			

The RHS value for the TF-34 Milling shop could be raised to the level of 855 hours with one extra Saturday shift of 21 people. Although this would not completely alleviate this constraint, it would make available 313.5 hrs of slack resources resulting in an increased revenue of $23,511.

This type of analysis only looks at changes to one constraint equation at a time. There could be pairs or sets of constraints that would provide greater profit maximization if reduced together.

APPENDIX I: REDUCTION OF ROUTING PARTS TO NDT

OPTIMAL PRODUCT MIX:

	Variable	Value	Cost	Red. cost	Status
8	214412010	10.0000	19.0000	-0.5938	Lower bound
9	214412020	16.0000	2.5300	0.4322	Upper bound
10	214412030	242.3506	0.8600	0.0000	Basic
12	214412050	18.0538	16.5300	0.0000	Basic
20	214413030	0.6468	57.2600	0.0000	Basic
21	214413040	12.0060	33.4800	0.0000	Basic
54	225211010	10.0000	23.2000	8.1035	Upper bound
60	225212020	30.0000	20.9200	0.1460	Upper bound
63	225212050	71.8259	17.3500	0.0000	Basic
64	225212060	1.0000	21.0000	-9.4883	Lower bound
70	225212094	33.0000	1.6100	0.3183	Upper bound
73	225213010	1.0000	5.8200	-2.0097	Lower bound
76	225213030	1.0000	54.7200	-7.7052	Lower bound
77	225213040	1.0000	44.1100	-18.0223	Lower bound
81	BLADE SET	154.4893	0.9200	0.0000	Basic
84	225215040	60.8336	0.5800	0.0000	Basic
93	225215130	29.5717	28.9200	0.0000	Basic
97	22521CAN0	18.0000	5.6800	1.9732	Upper bound
98	T-56	5.0000	558.3200	242.1101	Upper bound
99	TF-34	1.0000	635.7600	200.0758	Upper bound

Objective Function Value = 8023.116

As compared to the initial objective function value of 7893.7 (Appendix F) decreasing all products need for the initial NDT and resultant clean operation by five percent would enable an increase of 129.4 hours of otherwise slack production. This rise to 8023.1 hours, would yield increased revenue of $9,705 per week.

Per the Theory of Constraints, when one constraint is elevated (alleviated) another constraint will appear. The number of constraints in the powerplants system has grown from six to eight in the process of attempting to alleviate Cleaning and NDT as constraints. The appearance

CONSTRAINT RESOURCES:

	Constraint	Type	RHS	Slack	Shadow price
1	PLATING	<=	1020.0000	519.2883	0.0000
2	FIBER GLAS	<=	340.0000	317.8600	0.0000
3	INFLT REFU	<=	306.0000	304.6300	0.0000
4	NAV COMP	<=	306.0000	304.3300	0.0000
5	E&E T56	<=	510.0000	371.0500	0.0000
6	COMP T56	<=	612.0000	308.4243	0.0000
7	T56 POWER	<=	884.0000	214.3500	0.0000
8	T56 MACH	<=	884.0000	791.6007	0.0000
9	T56 F/C	<=	204.0000	198.8300	0.0000
10	BEARING	<=	306.0000	225.8400	0.0000
11	E&E TF34	<=	374.0000	287.8786	0.0000
12	**NDT**	<=	578.0000	0.0000	**2.7554**
13	**WELD**	<=	476.0000	0.0000	**0.9991**
14	HEAT TREAT	<=	136.0000	39.6845	0.0000
15	**COMP TF34**	<=	612.0000	0.0000	**0.8654**
16	**TURB TF34**	<=	578.0000	0.0000	**0.1647**
17	**CLEAN**	<=	442.0000	0.0000	**1.3601**
18	BLAST	<=	272.0000	159.2081	0.0000
19	TF34 ASSY	<=	714.0000	354.5700	0.0000
20	TF34 LATHE	<=	612.0000	133.7343	0.0000
21	**TF34 MILL**	<=	714.0000	0.0000	**2.4132**
22	**METAL SPRA**	<=	510.0000	0.0000	**1.0801**
23	TF34 MACH	<=	442.0000	392.8700	0.0000
24	E&E PNEUD	<=	170.0000	113.4412	0.0000
25	FP ACC IGN	<=	646.0000	387.1586	0.0000
26	**F/C ACC IG**	<=	714.0000	0.0000	**1.3296**
27	PUMPS CONT	<=	442.0000	350.0700	0.0000

of Welding and the TF-34 Turbine shop as constraints will direct our attention to these shops as strategically important to process improvement and a more focused, in-depth analysis as well.

If 10 percent of all products can skip the initial NDT and resultant clean operation, 216.9 hours of additional production can be realized over the initial analysis. This improvement would be worth $16,267.5 per week (again based on a rough estimate of 75$/hr).

10 PERCENT LESS CLEANING AND NDT ON ALL PRODUCTS

OPTIMAL PRODUCT MIX:

	Variable	Value	Cost	Red. cost	Status
8	214412010	11.8088	19.0000	0.0000	Basic
9	214412020	16.0000	2.5300	1.1524	Upper bound
10	214412030	336.0000	0.8600	0.1645	Upper bound
12	214412050	23.1086	16.5300	0.0000	Basic
20	214413030	0.9051	57.2600	0.0000	Basic
21	214413040	12.1537	33.4800	0.0000	Basic
54	225211010	10.0000	23.2000	7.7555	Upper bound
60	225212020	26.9123	20.9200	0.0000	Basic

63	225212050	71.8259	17.3500	0.0000	Basic
64	225212060	1.0000	21.0000	-10.7210	Lower bound
70	225212094	33.0000	1.6100	0.5628	Upper bound
73	225213010	1.0000	5.8200	-1.2116	Lower bound
76	225213030	1.0000	54.7200	-11.8500	Lower bound
77	225213040	1.0000	44.1100	-39.7918	Lower bound
81	BLADE SET	80.0000	0.9200	-0.2631	Lower bound
84	225215040	65.0000	0.5800	0.1868	Upper bound
93	225215130	29.5717	28.9200	0.0000	Basic
97	22521CAN0	18.0000	5.6800	0.9540	Upper bound
98	T-56	5.0000	558.3200	251.6163	Upper bound
99	TF-34	1.0000	635.7600	189.3519	Upper bound

Objective Function Value = 8110.603

At this point NDT has been completely eliminated as a constraint and the value (shadow price) of alleviating other constraints has increased. Thus strategically important process improvements must be looked for elsewhere. This is the strength of linear programming, being able to identify where strategic improvements should be made.

CONSTRAINT RESOURCES:

	Constraint	Type	RHS	Slack	Shadow price
1	PLATING	<=	1020.0000	525.7267	0.0000
2	FIBER GLAS	<=	340.0000	317.8600	0.0000
3	INFLT REFU	<=	306.0000	304.6300	0.0000
4	NAV COMP	<=	306.0000	304.3300	0.0000
5	E&E T56	<=	510.0000	371.0500	0.0000
6	COMP T56	<=	612.0000	303.2455	0.0000
7	T56 POWER	<=	884.0000	214.3138	0.0000
8	T56 MACH	<=	884.0000	790.5643	0.0000
9	T56 F/C	<=	204.0000	198.8300	0.0000
10	BEARING	<=	306.0000	225.8400	0.0000
11	E&E TF34	<=	374.0000	289.0088	0.0000
12	NDT	<=	578.0000	11.2989	0.0000
13	**WELD**	<=	476.0000	0.0000	**1.2739**
14	HEAT TREAT	<=	136.0000	19.8070	0.0000
15	COMP TF34	<=	612.0000	0.0000	**1.8046**
16	**TURB TF34**	<=	578.0000	0.0000	**1.1738**
17	**CLEAN**	<=	442.0000	0.0000	**2.2229**
18	BLAST	<=	272.0000	148.2279	0.0000
19	TF34 ASSY	<=	714.0000	357.2872	0.0000
20	TF34 LATHE	<=	612.0000	118.1855	0.0000
21	**TF34 MILL**	<=	714.0000	0.0000	**2.6262**
22	**METAL SPRA**	<=	510.0000	0.0000	**0.6846**
23	TF34 MACH	<=	442.0000	392.8700	0.0000
24	E&E PNEUD	<=	170.0000	113.4412	0.0000
25	FP ACC IGN	<=	646.0000	387.1586	0.0000
26	**F/C ACC IG**	<=	714.0000	0.0000	**1.3343**
27	PUMPS CONT	<=	442.0000	350.0700	0.0000

APPENDIX J: VARIATION IN ARRIVAL AND PROCESSING TIMES

The below data was collected by talking with shop workers on the quantities of T-56 turbine rotor parts they processed per hour, day, week, etc. Eight questions were asked to derive the below information. The questions were constructed to ascertain the mean, the range and median arrival and processing times for these parts.

Turbine #1-Assembly EXAMINATION & EVALUATION

BATCH SIZE: turbine assy.
AVERAGE ARRIVAL RATE: 4/day
LOWEST ARRIVAL RATE: 0/day
HIGHEST ARRIVAL RATE: 8/day
MOST FREQUENT ARRIVAL RATE: 6/day

AVERAGE PROCESSING TIME: 0.5 hrs
LOWEST (FASTEST) PROCESSING TIME: 0.25 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 3.0 hrs
MOST FREQUENT PROCESSING TIME: same as avg.

Turbine #2-Assembly DISASSEMBLE

BATCH SIZE: turbine assy.
AVERAGE ARRIVAL RATE: 2/day
LOWEST ARRIVAL RATE: 0/day
HIGHEST ARRIVAL RATE: 20/day
MOST FREQUENT ARRIVAL RATE: 4/day

AVERAGE PROCESSING TIME: 2.75 hrs
LOWEST (FASTEST) PROCESSING TIME: 0.5 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 8.0 hrs
MOST FREQUENT PROCESSING TIME: 3.0 hrs

Discs and Spacers to **#3-Discs**

#3-1,2,3,4

*** CLEANING**

BATCH SIZE: 5-10 baskets/pallet
AVERAGE ARRIVAL RATE: 2 pallets/day
LOWEST ARRIVAL RATE: 0 pallets/day
HIGHEST ARRIVAL RATE: 6 pallets/day
MOST FREQUENT ARRIVAL RATE: 3 pallets/day

AVERAGE PROCESSING TIME: 1.0 hrs
LOWEST (FASTEST) PROCESSING TIME: 0.5 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 4.0 hrs
MOST FREQUENT PROCESSING TIME: same as avg.
* limit is 18 baskets at one time

#4-1,2,3,4
BLASTING

BATCH SIZE: 1 basket
AVERAGE ARRIVAL RATE: 12 baskets/day
LOWEST ARRIVAL RATE: 0 baskets/day
HIGHEST ARRIVAL RATE: 30 baskets/day
MOST FREQUENT ARRIVAL RATE: 10 baskets/day

AVERAGE PROCESSING TIME: 1.0 hrs
LOWEST (FASTEST) PROCESSING TIME: 0.5 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 2.0 hrs
MOST FREQUENT PROCESSING TIME: same as avg.

3rd & 4th stage blades to **#5-3,4**

#5-1,2
INSPECTION & REWORK (MINOR BLENDING ONLY)

BATCH SIZE: 1 basket
AVERAGE ARRIVAL RATE: 6 baskets/day
LOWEST ARRIVAL RATE: 0 baskets/day
HIGHEST ARRIVAL RATE: 14 baskets/day
MOST FREQUENT ARRIVAL RATE: 4 baskets/day

AVERAGE PROCESSING TIME: 0.75 hrs
LOWEST (FASTEST) PROCESSING TIME: 0.42 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 2.0 hrs
MOST FREQUENT PROCESSING TIME: 0.58 hrs

1ST STAGE 35% SCRAP
2ND STAGE 20% SCRAP

#6-1,2
NONDESTRUCTIVE TESTING (USING FLUORESCENT DIE PENETRANT

BATCH SIZE: 1 basket
AVERAGE ARRIVAL RATE: 4 baskets/day
LOWEST ARRIVAL RATE: 0 baskets/day
HIGHEST ARRIVAL RATE: 18 baskets/day
MOST FREQUENT ARRIVAL RATE: 8 baskets/day

AVERAGE PROCESSING TIME: 1.67 hrs
LOWEST (FASTEST) PROCESSING TIME: 1.57 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 16.0 hrs
MOST FREQUENT PROCESSING TIME: 2.0 hrs

#7-1,2
*** VAPOR DEGREASE**

BATCH SIZE: 6-10 baskets/pallet
AVERAGE ARRIVAL RATE: 2 pallets/day
LOWEST ARRIVAL RATE: 0 pallets/day
HIGHEST ARRIVAL RATE: 3 pallets/day
MOST FREQUENT ARRIVAL RATE: 1 pallet/day

AVERAGE PROCESSING TIME: .25 hrs
LOWEST (FASTEST) PROCESSING TIME: .2 hrs
HIGHEST (SLOWEST) PROCESSING TIME: .5 hrs
MOST FREQUENT PROCESSING TIME: same as avg.

* limit is 18 baskets at one time

#8-1,2
BLASTING
(ALUM. OXIDE)

BATCH SIZE: 4-10 baskets/pallet
AVERAGE ARRIVAL RATE: 2 pallets/day
LOWEST ARRIVAL RATE: 0 pallets/day
HIGHEST ARRIVAL RATE: 3 pallets/day
MOST FREQUENT ARRIVAL RATE: 1 pallet/day

AVERAGE PROCESSING TIME: .75 hrs
LOWEST (FASTEST) PROCESSING TIME: .30 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 1.50 hrs
MOST FREQUENT PROCESSING TIME: same as avg.

#9-1,2
HEAT
TINT *

BATCH SIZE: 1-14 baskets per pallet
AVERAGE ARRIVAL RATE: 2-3 pallets/week
LOWEST ARRIVAL RATE: 0 pallets/month
HIGHEST ARRIVAL RATE: 5 pallets/week
MOST FREQUENT ARRIVAL RATE: same as avg.

AVERAGE PROCESSING TIME: 3 hrs
LOWEST (FASTEST) PROCESSING TIME: 1 hr
HIGHEST (SLOWEST) PROCESSING TIME: 40 hrs
MOST FREQUENT PROCESSING TIME: 2 hrs
*maximum capacity 12 baskets

#10-1,2
INSPECT
COLOR

BATCH SIZE: basket
AVERAGE ARRIVAL RATE: 4 baskets
LOWEST ARRIVAL RATE: 0 baskets
HIGHEST ARRIVAL RATE: 6 baskets
MOST FREQUENT ARRIVAL RATE: 4 baskets

AVERAGE PROCESSING TIME: .60 hrs
LOWEST (FASTEST) PROCESSING TIME: .33 hrs
HIGHEST (SLOWEST) PROCESSING TIME: 3.3 hrs
MOST FREQUENT PROCESSING TIME: same as avg.

20% OK
#11A-1,2
STORE FOR
BUILDING

50% SERVICE
#11B-1,2
AEP COATING
PROCESS

#12B-1,2
STORE FOR
BUILDING

30% BAD
#11C-1,2
SCRAP

APPENDIX K: INPUT TO MPX

OPERATION TIME UNIT		HOUR
FLOW TIME UNIT		DAY
DEMAND PERIOD		QUARTER
Manufacturing Facility Operating Times		
HOUR/DAY WORKED		16.00
DAY/QUARTER WORKED		61.00
MAX. EQUIPMENT UTILIZATION	95.00%	
VARIABILITY IN ARRIVAL	30.00%	
VARIABILITY IN LABOR	30.00%	
VARIABILITY IN EQUIPMENT	30.00%	

Figure K-1. Time Data

LABOR GROUP NAME	# OF OPERATORS PRESENT AT A TIME	% TIME UNAVAIL-ABLE	% OVER-TIME	SET-UP TIME FACTOR	RUN TIME FACTOR	VARIA-BILITY FACTOR
METAL10	4	0.16	0.0	1.0	1.0	1.0
MACHINIST	3	0.16	0.0	1.0	1.0	1.0

Note: There are eight metalists assigned to this work center, five on days and three on swing shift. Six of the workers are WG-10's and two are WG-8's. The model assumed every worker could perform the same task and that there were four on day and swing shift.

Figure K-2. Labor Data List

EQUIPMENT GROUP NAME	NUMBER IN GROUP	RELIABILITY MTTF	MTTR -- HOURs --	% OVER-TIME	LABOR GROUP ASSIGNED	SET-UP TIME FACTOR	RUN TIME FACTOR	VARIA-BILITY FACTOR
WIRE SPRAY	2	60.0	30.0	0.00	METAL10	1.00	1.00	1.0
PLASMA	3	320.0	5.0	0.00	METAL10	1.00	1.00	1.0
OVEN	3	320.0	28.0	0.00	METAL10	1.00	1.00	1.0
BLAST	3	160.0	40.0	0.00	METAL10	1.00	1.00	1.0
THERMO	5	320.0	4.0	0.00	METAL10	1.00	1.00	1.0
DEGREASE	1	1000.0	1.0	0.00	METAL10	1.00	1.00	1.0
BENCH	6	10000	0.1	0.00	METAL10	1.00	1.00	1.0
PRES CHK	1	1000.0	0.1	0.00	METAL10	1.00	1.00	1.0
MACH	3	1000.0	1.0	0.00	MACHINIST	1.00	1.00	1.0

Figure K-3. Equipment Data List

The equipment failure rates were based on estimates obtained from the workers. The variability coefficients for labor set-up time, equipment run time, and arrivals were left at the default setting of 1.0. The part names were constructed using T for T-56, G for T-56 RGB and F for the TF-34. This is followed by the Component Identification Number (CIN).

PART NAME	END USE DEMAND	LOT SIZE	TRANSFER BATCH SIZE	DEMAND FACTOR	ARRIVAL VARIABLITY FACTOR
T1040-8 RG	5	1	-1	1.0	1.0
G4010-4 DI	7	1	-1	1.0	1.0
F2050-1 SE	5	1	-1	1.0	1.0
T2010-1 CA	144	3	-1	1.0	1.0
T3020-1 DI	23	2	-1	1.0	1.0
T3040-0 CA	100	4	-1	1.0	1.0
T3052-0 HO	1	1	-1	1.0	1.0
G4010-1 HO	48	2	-1	1.0	1.0
G4010-2 DI	48	2	-1	1.0	1.0
G4010-3 HO	48	2	-1	1.0	1.0
G4080-7 BU	48	4	-1	1.0	1.0
F3030-1 SP	65	5	-1	1.0	1.0
F3040-1 CA	22	5	-1	1.0	1.0
F3050-1 CA	12	1	-1	1.0	1.0
F5010-2 DI	12	1	-1	1.0	1.0
F2010-1 SE	22	5	-1	1.0	1.0
F2060-2 SU	131	7	-1	1.0	1.0
F2081-7 SE	12	4	-1	1.0	1.0
F2095-7 SE	12	1	-1	1.0	1.0

Figure K-4. Part Data List

OPERATION NAME	EQUIPMENT NAME	% ASSIGNED	TOTAL TIME AT EQUIP ----- (HOUR) ------ SET-UP TIME/LOT	RUN TIME/PC	LABOR TIME AT EQUIP ----- (HOUR) ------- SET-UP TIME/LOT	RUN TIME/PC
DEGREASE	DEGREASE	100.0	0.00	0.08	0.00	0.08
BAKE	OVEN	100.0	0.03	1.00	0.03	0.00
MASK	BENCH	100.0	0.05	1.00	0.05	1.00
BLAST	BLAST	100.0	0.02	0.25	0.02	0.25
PREHEAT	OVEN	100.0	0.02	0.25	0.02	0.10
SPRAY	WIRE SPRAY	5.0	0.30	0.20	0.17	0.20
SPRAY	THERMO	75.0	0.30	0.20	0.17	0.20
SPRAY	PLASMA	20.0	0.30	0.20	0.17	0.20
CHIP,CHK,D	BENCH	100.0	0.00	0.17	0.00	0.17

FROM OPERATION	TO OPERATION	% FOLLOWING
DOCK	DEGREASE	100.0
DEGREASE	BAKE	100.0
BAKE	MASK	100.0
MASK	BLAST	100.0
BLAST	PREHEAT	100.0
PREHEAT	SPRAY	100.0
SPRAY	CHIP,CHK,DE	100.0
CHIP,CHK,DE	STOCK	100.0

-- Note: Most unrepairable parts are detected and scrapped prior to the metal spray work center. No scrap was assumed generated in the work center, thus 100% of parts were modeled to follow from one operation to the next.

Figure K-5. Operation Assignment Data for Example Part T1040-8, RGB Housing

OPERATION NAME	EQUIPMENT NAME	% ASSIGNED	TOTAL TIME AT EQUIP (HOUR) SET-UP TIME/LOT	TOTAL TIME AT EQUIP (HOUR) RUN TIME/PC	LABOR TIME AT EQUIP (HOUR) SET-UP TIME/LOT	LABOR TIME AT EQUIP (HOUR) RUN TIME/PC
DEGREASE	DEGREASE	100.0	0.00	0.08	0.00	0.08
BAKE	OVEN	100.0	0.03	3.00	0.03	0.02
MASK	BENCH	100.0	0.05	1.00	0.05	1.00
PREHEAT	OVEN	100.0	0.02	0.30	0.02	0.30
SPRAY	WIRE SPRAY	100.0	0.50	4.25	0.17	4.25
CHIP, CHK	BENCH	100.0	0.25	0.08	0.17	0.08
CLEAN	DEGREASE	100.0	0.02	0.19	0.02	0.19
RETORQUE	BENCH	100.0	0.02	0.50	0.02	0.50
MACH	MACH	100.0	0.50	1.50	0.50	1.50
CLEAN2	DEGREASE	100.0	0.00	0.08	0.00	0.08
BAKE2	OVEN	100.0	0.03	3.00	0.03	0.02
MASK2	BENCH	100.0	0.05	1.00	0.05	1.00
PREHEAT2	OVEN	100.0	0.02	0.30	0.02	0.30
SPRAY2	WIRE SPRAY	100.0	0.50	4.00	0.17	4.00
CHIP2,CHK	BENCH	100.0	0.25	0.08	0.17	0.08
RETORQUE2	BENCH	100.0	0.02	0.50	0.02	0.50

FROM OPERATION	TO OPERATION	% FOLLOWING
DOCK	DEGREASE	100.0
DEGREASE	BAKE	100.0
BAKE	MASK	100.0
MASK	PREHEAT	100.0
PREHEAT	SPRAY	100.0
SPRAY	CHIP, CHK	100.0
CHIP, CHK	CLEAN	100.0
CLEAN	RETORQUE	100.0
RETORQUE	MACH	100.0
MACH	CLEAN2	100.0
CLEAN2	BAKE2	100.0
BAKE2	MASK2	100.0
MASK2	PREHEAT2	100.0
PREHEAT2	SPRAY2	100.0
SPRAY2	CHIP2,CHK	100.0
CHIP2,CHK	RETORQUE2	100.0
RETORQUE2	STOCK	100.0

Note: The routings in this model were obtained by talking with workers in the metal spray work center. Many of the set-up times per lot and per component were estimated by the author based on similar parts, in absence of available interface time to collect data.

Figure K-6. Operation Assignment Data for Example Part T3040-0 Case Assembly

APPENDIX L: WHAT-IF ANALYSIS OF METAL SPRAY WORK CENTER

With the base case data as shown in Appendix K, MPX was not able to produce a feasible solution in which the highest utilization of any equipment was less than 95% (to cover for planned maintenance). The bar graph shows that a total of 98% of the available wire spray machine time consists of set-up time, run time, waiting for labor time, and down time.

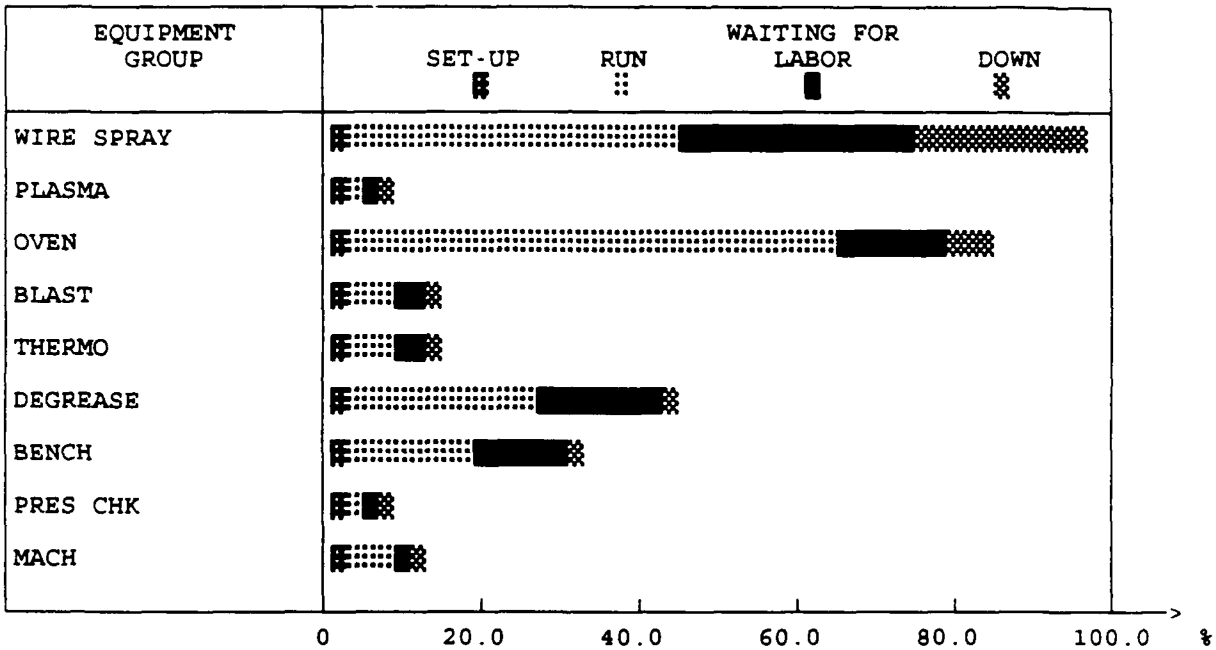


Figure L-1. Equipment Utilization on Base Case

In the first what-if case the MTBF of the wire spray machine was increased to 70 hours and the MTTR was decreased to 20 hours. This change is a hypothetical improvement that produced the feasible solution.

The queuing network produced feasible results after the reliability and maintainability of the wire spray machine was improved. Figure L-2 shows the percent of capacity required of the equipment. The report on production, WIP, and flow time is shown in Appendix M.

EQUIPMENT GROUP NAME	% of CAPACITY REQUIRED FOR SETUP	FOR RUN	WAIT FOR LABOR	EQUIP DOWN	TOTAL	
WIRE SPRAY	1.3	42.7	31.1	12.6	87.7	- Feasible (<95%)
PLASMA	0.6	1.4	1.0	0.031	3.0	
OVEN	0.4	64.2	13.3	5.7	83.6	
BLAST	0.1	5.7	4.2	1.4	11.4	
THERMO	1.7	5.7	3.2	0.093	10.7	
DEGREASE	0.2	23.6	17.1	0.024	40.9	
BENCH	0.5	16.3	12.0	0.00017	28.7	
PRES CHK	0.047	0.2	0.2	0.000028	0.5	
MACH	0.4	5.2	0.0090	0.0056	5.6	

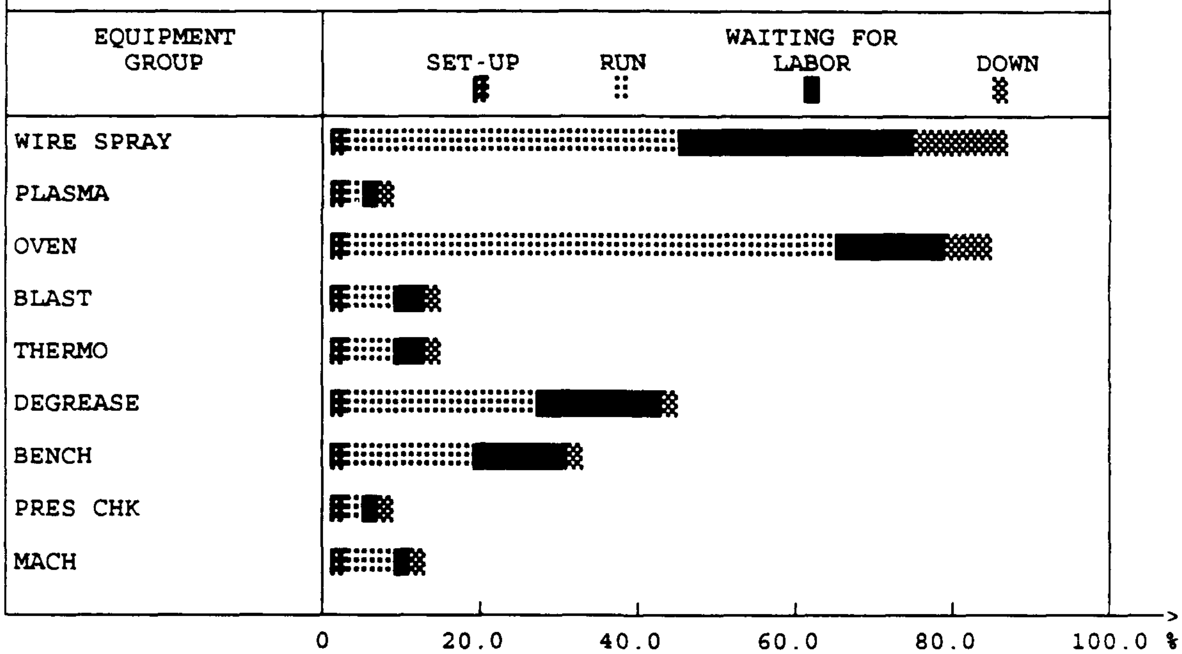


Figure L-2. What-if case #1 Equipment Utilization Report

The specific changes to the base case are shown in Figure L-3.

EQUIPMENT DATA			
EQUIPMENT	FIELD	BASE CASE	WHAT-IF
WIRE SPRAY	MTTF	60.000000	70.000000
WIRE SPRAY	MTTR	30.000000	20.000000

PART DATA			
PART	FIELD	BASE CASE	WHAT-IF
T2010-1 CA	LOT SIZE	3.000000	2.000000
T3040-0 CA	LOT SIZE	4.000000	2.000000
G4080-7 BU	LOT SIZE	4.000000	2.000000
F3030-1 SP	LOT SIZE	5.000000	2.000000
F3040-1 CA	LOT SIZE	5.000000	2.000000
F2010-1 SE	LOT SIZE	5.000000	2.000000
F2060-2 SU	LOT SIZE	7.000000	2.000000
F2081-7 SE	LOT SIZE	4.000000	2.000000

Figure L-3. What-if Case #2 - Decreasing Batch Sizes

Although the resultant utilization for wire spray is over 95% as shown in Figure L-4, the increased demand should be capable of being handled with further improvements to the reliability and maintainability and improvement efforts in set-up time reduction.

EQUIPMENT GROUP NAME	% of CAPACITY REQUIRED FOR SETUP	FOR RUN	WAIT FOR LABOR	EQUIP DOWN	TOTAL	
WIRE SPRAY	2.6	42.7	38.8	12.9	97.0	- over 95%
PLASMA	0.8	1.4	1.4	0.034	3.6	
OVEN	0.6	64.2	16.6	5.7	87.1	
BLAST	0.2	5.7	5.2	1.5	12.5	
THERMO	2.7	5.7	4.3	0.1	12.8	
DEGREASE	0.3	23.6	21.2	0.024	45.0	
BENCH	0.8	16.3	15.0	0.00017	32.1	
PRES CHK	0.047	0.2	0.3	0.000028	0.5	
MACH	0.9	5.2	0.0097	0.0060	6.1	

Figure L-4. Equipment Utilization For Case #2 (Reduced Batch Sizes)

APPENDIX M: PRODUCTION REPORT FOR WHAT-IF CASE #1

The following production figures were made possible in what-if case #1. The flow times for the case assembly and external compressor housing are relatively high. The flow time for the entire T-56 engine overhaul process is an average of 47 days as shown in Appendix A.

PART NAME	TOTAL PRODCTN	END USE PRODCTN	W-I-P IN PIECES	FLOW TIME IN DAYS
T1040-8 RGB HOUS	5.0	5.0	0.1	1.7
G4010-4 DIA RE G CA	7.0	7.0	0.2	1.7
F2050-1 SEAL 4LPT	5.0	5.0	0.1	1.6
T2010-1 CASE, TI	144.0	144.0	5.3	2.3
T3020-1 DIFFUSER C	23.0	23.0	0.7	1.8
T3040-0 CASE ASBLY	100.0	100.0	32.0	19.5
T3052-0 HOUS COMPEX	1.0	1.0	0.2	13.6
G4010-1 HOUS, FRONT	48.0	48.0	1.8	2.3
G4010-2 DIA F ASSS	48.0	48.0	1.8	2.3
G4010-3 HOUS ASY RE	48.0	48.0	1.8	2.3
G4030-7 BULL GEAR	48.0	48.0	2.5	3.2
F3030-1 SPOOL CR	65.0	65.0	3.2	3.0
F3040-1 CASE, COM F	22.0	22.0	1.0	2.9
F3050-1 CASE, COM R	12.0	12.0	0.3	1.6
F5010-2 DISK AS FAN	12.0	12.0	0.3	1.6
F2010-1 SEAL,RO AIR	22.0	22.0	1.0	2.8
F2060-2 SUPPORT B	131.0	131.0	7.2	3.4
F2081-7 SEAL ASSY	12.0	12.0	0.5	2.5
F2095-7 SEAL, INNER	12.0	12.0	0.3	1.6

Figure M-1. Part Summary Report

EQUIPMENT GROUP NAME	TOTAL UTILIZATION %	TOTAL W-I-P (PIECES)
WIRE SPRAY	87.7	21.8
PLASMA	3.0	0.3
OVEN	83.6	25.3
BLAST	11.4	1.3
THERMO	10.7	2.2
DEGREASE	40.9	2.7
BENCH	28.7	6.2
PRES CHK	0.5	0.0098
MACH	5.6	0.7

Figure M-2. Equipment Summary Report

LABOR GROUP NAME	TOTAL UTIL %
METAL10	77.6
MACHINIST	5.8

Figure M-3. Labor Util

Note: The T3040-0 case assembly interacts with the machine shop before it completes processing in metal spray.

In practice someone highly familiar with the processes and where process improvements could be made, would propose reasonable improvements to bottleneck related processes.

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